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MISSILE SYSTEM SAFETY

AN EVALUATION OF SYSTEM TEST DATA

(Atlas MA-3 Engine System)

ROM 3181-1001

human factors

PERSONNEL SUBSYSTEMS REPORT

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MISSILE SYSTEM SAFETY: AN EVALUATION OF SYSTEM TEST DATA (ATLAS MA-3 ENGINE SYSTEM)

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC.
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Contract AF04(694)-8

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MISSILE SYSTEM SAFETY

AN EVALUATION OF SYSTEM TEST DATA

(Atlas MA-3 Engine System)

GEORGE A. PETERS
and
FRANK S. HALL

ROM 3181-1001
1 MARCH 1963

RELIABILITY OPERATIONS - HUMAN FACTORS
ROCKETDYNE ENGINEERING, CANOGA PARK, CALIFORNIA

ROCKETDYNE
A DIVISION OF NORTH AMERICAN AVIATION, INC

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FOREWORD

The purpose of this publication is to present detailed information concerning actual incidents and problems which have affected the operational safety of rocket engine systems. The test data contained in this report were collected and evaluated under the provisions of Contract AF04(694)-8, GM 6300.5-1060, GM 6300.3-2106, and Atlas SPO Category II Program Instructions.

CONTENTS

ILLUSTRATIONS

SECTION 1

INTRODUCTION

The purpose, approach, and importance of the study

This section contains introductory information regarding the basic purposes and objectives toward which this missile system safety study was oriented. The basic method or approach used to gather and interpret the data is described, and the relative importance of safety as a technical objective and the constituent factors of the safety variable are discussed.

INTRODUCTION

PART 1. PURPOSE OF THE STUDY

A significant amount of human factors data that pertained to missile system safety was accumulated during the course of various operational system test exercises. These data were in the form of incidents (deviations/difficulties), which were gathered during the direct observation of various job operations. Much of the basic data and the results of preliminary analyses have been reported previously in some 36 monthly periodic and logical function reports (Appendix E, List of OSTF Reports).

The purpose of this report is to provide additional pertinent information; it was obtained as a result of further updating and detailed analyses of the data, and oriented toward the following five objectives.

OVER-ALL ANALYSIS AND EVALUATION OF BASIC DATA

A review was made of all of the human factors incidents and problems that have affected the operational safety of the Atlas engine system. The information concerning each problem was updated, further analyses were made, supporting data were obtained, and a case study format was prepared. Each case study contains statements regarding the equipment affected, job operation involved, problem criticality, problem type, system implication, recommended corrective action, and a chronological indication of the current disposition. These problems were then critically examined to determine what new knowledge could be gained from these operational experiences.

PREVENT RECURRENCE OF PROBLEMS

There is a tendency for some problems to continue, recur, or be repeated by subsequent personnel, sites, and programs. To help prevent recurrence of problems, some form of experience retention is necessary to alert those responsible concerning specific problem areas or difficulties in attaining various technical objectives. This experience retention should include analysis of accumulated past data, translation into a form which would be most meaningful, and timely transmittal (or availability) to those who would be in a position to use such information profitably.

All too often, basic data from investigatory programs may be relegated to files where, hopefully, at some future time, it could be organized, analyzed, interpreted, and made available to others. However, the pressure of current activities and the gradual loss of pertinent integrating facts from the memory of those involved may result in the almost complete loss of valuable information that was obtained at considerable cost.

One of the principal objectives of this report, therefore, is to analyze these data before they become relegated to files and make the pertinent results available to those who can use them on the Atlas program and subsequent related programs.

INFORMATION FOR PLANNING A SYSTEM SAFETY ENGINEERING PROGRAM

Another objective was to explore the meaning and implications of the data in order to derive more general information on system development that could have some applicability to other programs. An attempt was made to derive both useful design and systems planning information. Although basic data are from the Atlas program, supplemental information from other programs was obtained where necessary to verify the generality of the emergent concepts. Particular emphasis was then placed on developing a general approach to a system safety engineering program that could eliminate or greatly reduce the effect of the operational problems described.

BASIC REFERENCE AND TRAINING MATERIAL

Although a great deal of discrete work relative to system safety engineering has been done on the Atlas program, no summary description nor cross referencing of this work exists for those who might wish to utilize this material.

This report contains such information as well as pertinent references to a number of applicable specifications, exhibits, technical papers, and related activities that could provide further useful information. An attempt was made to logically organize, digest, and concentrate information that could be of maximum value if this report were to be utilized as a reference source, and to include materials suitable for use in reliability or safety training courses.

DESCRIPTIVE AND EXPLANATORY INFORMATION

General approaches to system safety engineering, techniques for implementing such an effort, and methodological difficulties which have been and could be encountered are described. Ideas, concepts, and general information that could facilitate future planning, proposal efforts, coordination, or direction of effort in the area are discussed.

Section 5, Part 2, contains additional information on requirements for safety evaluation.

PART 2. METHOD OR APPROACH

SOURCE OF SYSTEM TEST DATA

Human factors-personnel subsystem data were obtained by interviews with personnel operating Rocketdyne equipment, by observation of all test operations involving Rocketdyne equipment, and by investigation of all deviations from standard procedures which involved Rocketdyne equipment or personnel. The specific tools which were used to gather and report the data included Personnel Performance checklists, Human Engineering checklists, Posttest Interview forms, Deviation/Difficulty reports, Problem Analysis reports, and Summary Analysis reports. Supplemental reference was made to failure reports, aptitude test results, field service reports, inspection and maintenance logs, and various Atlas Associate Contractor reports.

The system test data presented were obtained during operational system test exercises involving the Atlas MA-3 engine system during the period from October 1960 to November 1962. The incidents reported were personally observed by trained human factors observer/analysts during job operations at the following locations:

1. OSTF Engine Maintenance Area, Rocketdyne Van Nuys Facility, Van Nuys, California
2. 576th Strategic Missile Squadron, Missile Assembly and Maintenance Shop C (MAM II), Vandenberg AFB, California
3. 576th Strategic Missile Squadron, Launch Site C, Vandenberg AFB, California
4. OSTF-1 Launch Site, Vandenberg AFB, California
5. OSTF-2 Launch Site, Vandenberg AFB, California (corroborative data)

The test data were supplemented by data obtained from other operational sites (i.e., Category II test information) where some verification or further understanding of a general problem area was desirable. In some cases, the human factors case studies and analytic information presented reflect a continuous accumulation of information over a fairly long period of time. Where it would contribute to problem understanding or actions undertaken relative to a problem, the specific chronology of events is given. Additional support data from various sources are presented where needed to substantiate, illustrate, or extend the systems safety engineering analyses and evaluations.

TYPE OF INCIDENTS REPORTED

A human factors incident (deviation/difficulty) was reported whenever there was any unexpected interruption, time delay, error, difficulty, or change in the established sequence of work tasks caused by equipment, procedural, supply support, or operator difficulty. All incidents were reported even if they did not involve injury to personnel or damage to equipment or property. The primary concern was to identify what went wrong and how it might be corrected, rather than to establish blame or responsibility.

The following definition was utilized by operational system test observers:

> "A deviation/difficulty is any incident which occurs outside the standard, predicted, or expected template of human behavior (such as excessive time to complete a task, an identifiable difficulty in performing an assigned task, any pattern of behavior which could lead to undesirable system performance characteristics, or any act which leads to a human-initiated failure)."*

*ROM 2181-1002, Human Performance in the Atlas Engine Maintenance Area, by G. A. Peters, F. S. Hall, and C. A. Mitchell, Rocketdyne Reliability Engineering, 1 February 1962.

PART 3. VARIABLES AFFECTING HUMAN PERFORMANCE

A number of functional variables in the operational situation directly affect the performance of required work tasks. To assess the relative importance of these variables, each human factors problem was examined to determine if it bore some significant relationship to each of these functional variables. Figure 1 shows the results.

SAFETY

It can be seen in Fig. 1 that safety is a major problem area affecting the performance of work tasks. Approximately one out of every five problems involved safety. The relative proportion of safety problems did not diminish as system testing continued.

Safety problems were those which could result in accidental equipment damage, physical hazard, or personnel injury. The cause of the hazard could involve hardware design, system configuration, task sequence, procedures, materials, operations, or common personnel practices. It would remain a problem until it was clearly identified, understood, and the hazard minimized (consistent with operational needs).

TECHNICAL DATA

The predominant continuing contributing factor in the problems encountered (Fig. 1) was the technical data used to guide or support the required job performance. More than one third of the problems involved in some way the use of technical data such as technical manuals or operation and maintenance checklists.

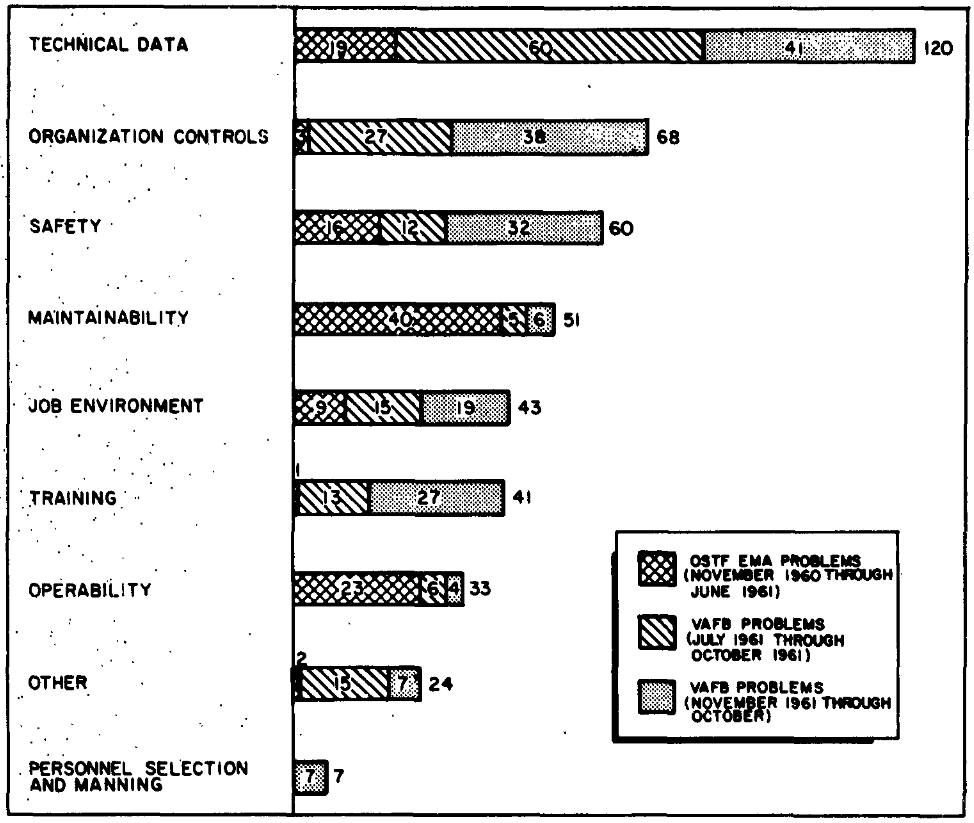

Figure 1 . Categorization of Human Factors Problems by Variables Affecting Human Performance

NOTE: N = 303. Each problem may be supported by a number of reported incidents (D/D's), and each problem could be related to one or more of the functional variables listed above. Chronology is based upon the initial report of the problem; subsequent incidents were reported only when they contributed in some way to the analysis or understanding of a problem, its causal effects, or the effectiveness of the corrective action.

Technical data problems were those in which some difficulty was experienced because of an omission, technical error, or lack of clarity in a technical manual, i.e., an individual's inability to understand the prescribed written procedure or his failure to find all the information required to complete a job task. More often, it involved an impractical sequencing of task elements or an erroneous assignment of these elements, e.g., employment of the wrong technical specialist.

ORGANIZATIONAL CONTROLS

Another major problem area (one of every five problems) involved organizational control procedures.

These problems involved the methods used for controlling activities of personnel in the work area, e.g., implementation of regulations, rules, or local policy that governed the employment of nonauthorized equipment or job practices. A problem could have involved:

1. The supervisory or administrative approach used to govern certain desired aspects of job performance
2. The application or use of procedural devices such as
    a. Operation and maintenance checklist
    b. Inspection work card
    c. Job manual procedure
    d. Regulation
    e. Policy

It would involve:

1. Shift assignment and rotation
2. Housekeeping standards
3. Standard operating procedures
4. Military discipline, etc.

which affect the manner in which work tasks are accomplished.

MAINTAINABILITY

A substantial number of maintainability problems were reported during the earlier maintenance demonstration exercises at the Van Nuys Engine Maintenance Area. The relative number of problems reported during subsequent operational system testing was much smaller (as would be expected).

The term "maintainability problem" was applied where characteristics or features of the equipment did not enhance the economical and effective accomplishment of maintenance tasks with the minimum time, skill, and resources in the operational environment. In addition to the obvious things, the problem may cause the mechanic to dislike performing maintenance operations on the equipment, encourage him to perform tasks in too great a hurry to accomplish them properly, or it may divert his attention to personal comfort or security when he should be attending to proper task performance or malfunction indications.

JOB ENVIRONMENT

Another variable or problem area which adversely affected personnel performance involved poor environmental conditions in the work area.

Job environment problems may involve:

1. Excessive noise
2. Poor illumination
3. Temperature and humidity extremes
4. Psychological pressure
5. Inadequate tools
6. Inappropriate test equipment
7. Crowded work space
8. Unsafe maintenance platforms

TRAINING

Problems involving the prior training of individuals performing various work tasks increased in relative importance during the conduct of operational system testing. These problems were related to discovered deficiencies in skills, job knowledge, and work habits, attitudes traceable to individual or integrated system training, or deficiencies more appropriately rectified by additional operational readiness training.

OPERABILITY

Operability problems were reported with greater frequency during the earlier EMA maintenance demonstration exercises. These problems relate to the tasks of activating, monitoring, regulating, or changing the performance of an item of equipment by means of controlling devices.

PERSONNEL SELECTION AND MANNING

Comparatively few problems were experienced in this area. These problems related to the selection or assignment of personnel to various job operations. A problem might have involved the number of persons assigned to do a job, the requirement for special aptitude or talent, or an apparent need to change existing personnel selection practices.

PART 4. SAFETY CRITICALITY AND ASSOCIATED FACTORS

SECONDARY FACTORS ASSOCIATED WITH SAFETY

Each of the 60 safety problems was reviewed to determine the general variables related to such problems (Fig. 2). Most of the equipment design problems were identified early in the system testing when intensive maintenance demonstration exercises were conducted. The major safety problems reported from the field site involved job environment, organizational controls, and training. There were 114 reported incidents (deviation/difficulties) on these 60 safety problems, i.e., an average of 1.9 reports per problem.

RELATIVE IMPORTANCE OF SAFETY VARIABLES

All problems, and the safety problems alone, were rated as to their relative importance or criticality (Fig. 3). Whereas 47 percent of all problems were rated of major importance, 68 percent of the safety problems were of major importance. In both cases, the problems initially reported during the later phases of the system testing were proportionally of greater criticality.

Since more than 13 percent of all problems reported have major safety implications, this area merits serious consideration of the contributing or causal factors and their amelioration.

For further information on safety criticality, see Section 3, Parts 1 and 2.

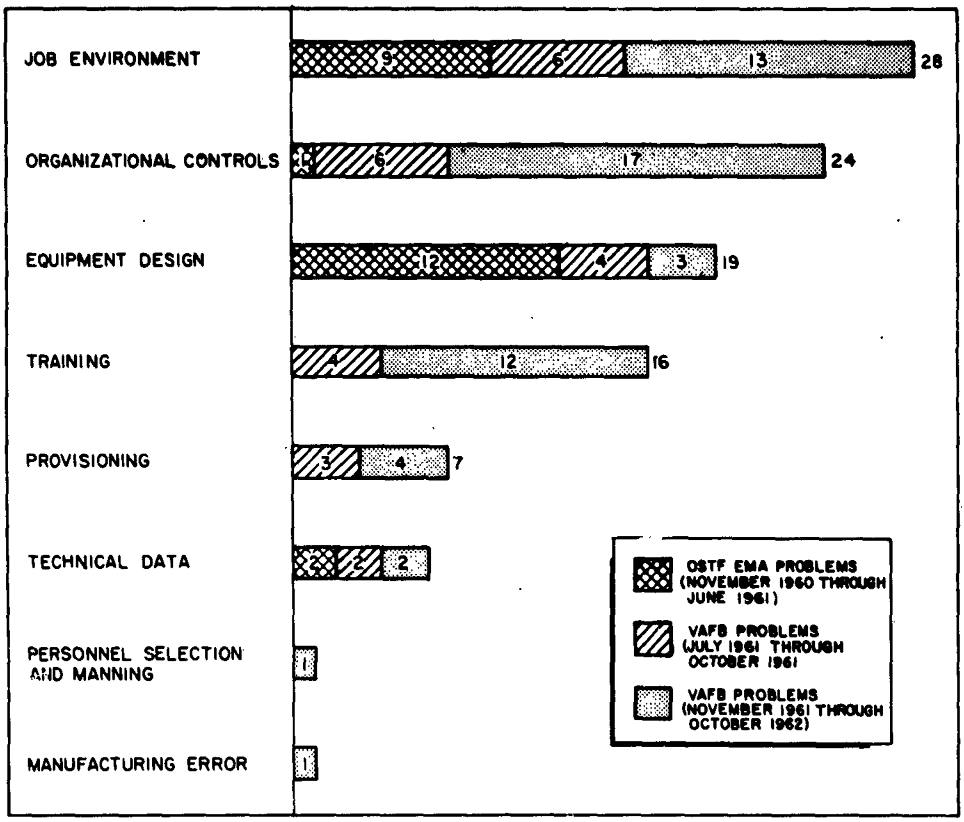

Figure 2. Categorization of Human Factors Problems Having Safety Implications (N = 60)

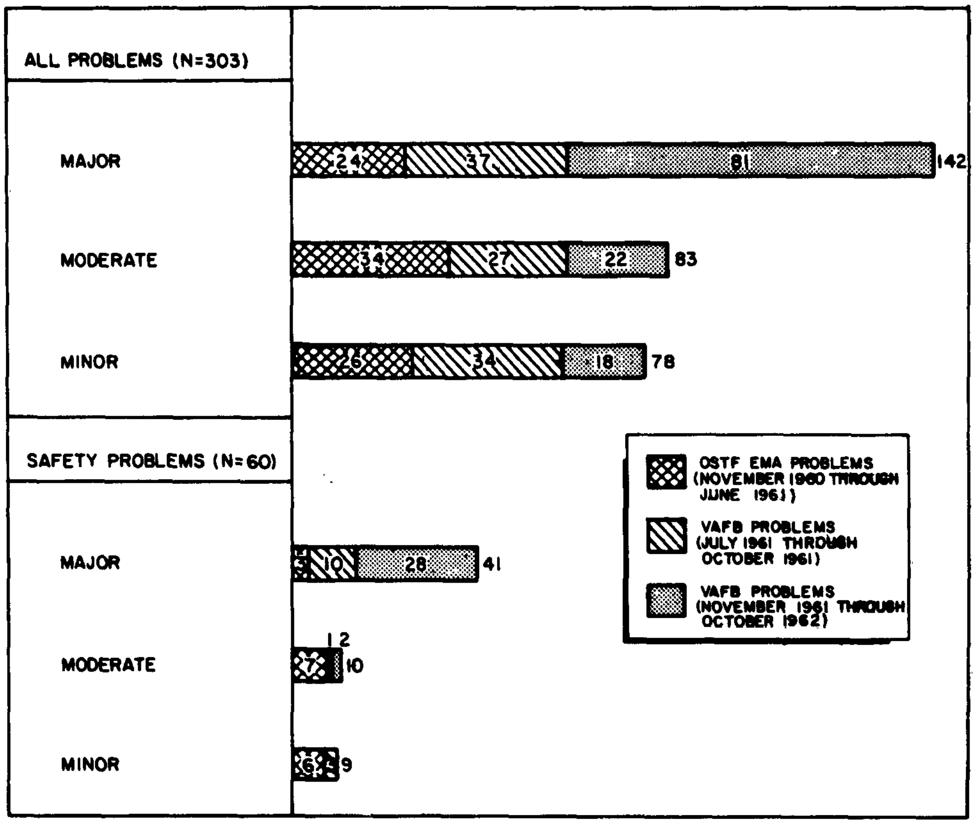

Figure 3. Criticality Rating of Human Factors Problems (OSTF-1 Only)

SECTION 2

CASE STUDIES

Safety data in the form of directly observed operational incidents.

In this section of the report, various operational problems reported by human factors observers during system test operations are described. These problems are presented in abbreviated case study fashion. Each problem contains a short description of the incidents, the equipment affected, the job operation/task involved, the type of problem and its criticality, the implications of the problem, the recommended corrective action, a chronological statement of the action taken, and some cross-reference notations.

CASE STUDIES

SAFETY PROBLEM NO. 1
(HUMAN FACTORS PROBLEM NO. 279)

SCHEDULING OF INCOMPATIBLE OPERATIONS

Incidents

Three crews were working simultaneously at the OSTF-1 launch site. One crew was attempting an engine flush and purge, another was performing ECP* modifications, and the third was draining the facility LO_2 (liquid oxygen) tank. Suddenly, the facility LO_2 tank vented, spilling clouds of GOX (gaseous oxygen) over the wall into the open missile bay where the other two crews were working. Fuel fumes are quite strong during early portions of an engine flush and purge, and operations stopped immediately as both crews quickly evacuated the area then, and each time thereafter that there seemed to be a possibility of again venting the LO_2 tank.

A second complication involved the fact that some of the ECP changes were on the flame bucket. It was difficult for the engine maintenance crew to keep from wetting the ECP crew with toxic trichloroethylene solvent or asphyxiating them with fumes.

Job Operation/Task

Checklist AP62-0132, Section 49-22, Engine Flush and Purge (4 June 1962); other tasks were not identified more specifically than indicated above.

*See appendix for list of abbreviations.

Problem Criticality

Major

Problem Type

Safety; Job Environment; Organizational Controls

System Implications

GOX was able to enter the missile bay from the facility LO_2 storage room because the roof was open when the missile was erected for the flush and purge. Any task in the missile bay, or which generates fuel fumes in the missile bay, and is performed with the overhead doors open is, therefore, incompatible with the task of draining the facility LO_2 storage tank. Likewise, any task on the lower portion of the launcher or in the flame bucket is incompatible with the engine flush and purge.

Recommended Corrective Action

Do not schedule incompatible tasks for simultaneous accomplishment.

Action Taken

Incident Report Number and Date	Disposition
D/D 6118R 2 July 1962	25 July 1962: PSRB assigned to OSTF-1 Site Commander with information copy going to 6595th Test Wing Safety Group. NOTE: The BSD Deputy IG for Safety at Norton AFB was on the distribution of the home plant OSTF reports which described this and other safety problems encountered.

SAFETY PROBLEM NO. 2
(HUMAN FACTORS PROBLEM NO. 111)

INFLATING THE THROAT PLUG TIRE

Incident

While attempting to inflate the throat plug tire, the MET/M connected the NCU line to the bleed fitting on the handle of the sustainer engine thrust chamber throat plug (instead of the tire Schraeder valve).

Job Operation/Task

Preparing the missile for MAPCHE checkout at launch site, T.O. 21-SM65E-CL-14-

Problem Criticality	Problem Type
Major	Safety; Training

System Implications

Fortunately, the human factors observer informed the MET/M of his error before pneumatic pressure was applied. Otherwise, the throat plug could have been blown out, with probable major damage to engine, throat plug, and RPIE, and with possible fatal injury to personnel. It is customary for such procedures to be accomplished from operational checklists where detailing of procedures is usually to be avoided. Therefore, the proposed addition of warning notes to job manuals would not solve the problem completely: the technician must be familiar enough with the equipment to recognize a need to consult the job manuals.

Recommended Corrective Action

Revise individual training for MET/M to include: (1) practice in throat plug insertion and tire inflation, (2) internal details of throat plug construction, and (3) knowledge of hazard created by applying tire inflation pressure to the thrust chamber by means of bleed fitting. Inform field personnel already graduated from individual training of (2) and (3); and include appropriate warning notes in Rocketdyne manuals to the integrating contractor. For future design, a more convenient and obvious location for the tire inflation valve and clear identification of all ports is recommended.

Action Taken

Incident Report Number and Date	Disposition
D/D 616R 13 July 1961	6 September 1961: Information copy of D/D to ATC for upgrading training package December 1961: Article "Inflating Thrust Chamber Throat Plug Tire" appeared in R/NAA Service News, page 3 7 December 1961: revision to R1469P-6-8 (checklist) contained the suggested warning notes 13 December 1961: revision to R1469P-2-25 (checklist) contained the requested warning notes

SAFETY PROBLEM NO. 3
(HUMAN FACTORS PROBLEM NO. 19)

OVERPRESSURIZATION DURING ENGINE FLUSH AND PURGE

Incidents

The MET/M was unable to set the specified purge pressures within a reasonable length of time. The various purging tasks required setting dynamic purge pressures ranging from 40 to 260 ±10 psig. The loaders used to set these pressures were designed for 0 to 6000 psig operating pressure range, which made the loaders too sensitive for making the required settings within the allowable tolerances with ease. Several cycles of overshooting and undershooting were observed before the desired settings were obtained.

Equipment Affected

Rocket engine lubricating-purging service unit AF/M46M-1.

Job Operation/Tasks

1. Flush and purge booster engines
2. Flush and purge sustainer engine
3. Purge vernier engines

Problem Criticality

Equipment Design (Operability); Safety

Problem Type

Equipment Design (Operability); Safety

System Implications

Problems of this type are difficult to avoid when equipment delivery dates are scheduled ahead of the firming up of system requirements. In other words, when an AGE item is designed to take care of all possibilities, it sometimes must be modified to do a better job when actual requirements become firm.

The identification and maintenance deficiencies reported in Human Factors Problems 57 and 291 cause this problem to be even more hazardous. They introduce the possibility that the system being purged may not be properly protected from the consequences of overpressurization with relief valves.

Recommended Corrective Action

Modify delivered equipment.

Action Taken

Incident Report Number and Date	Disposition
Van Nuys EMA Testing SE No. 5, January 1961	23 March 1961, MCR MA2-178 (30 November 1960) revised and reactivated for proposing a retrofit of loaders with 0 to 800 psig operating pressure range
D/D 4921R, 18 November 1961	31 July 1961, technical approval from BSD (received 30 August 1961)
	10 November 1961, TCTO 35E22-2-5-514, published and released to accomplish this change

SAFETY PROBLEM NO. 4
(HUMAN FACTORS PROBLEM NO. 230)

COMPOUNDING PROCEDURAL ERRORS

Incidents

A series of six major procedural errors were made by Air Force and civilian technicians resulting in hardware damage and an extra week of downtime for missile 66E. These errors began during sustainer engine system checkout when the hydraulic control package failed to open the head suppression valve and had to be replaced. The approved remove-and-replace procedure was not followed and somehow* the sustainer engine hydraulic accumulator was not properly recharged. This was the first error.

When hydraulic system pressure was applied, the accumulator developed a leak and had to be replaced. The crew replaced it with the one from the previously inspection rejected hydraulic control package. The second error was in using components from a rejected assembly. The third error was in breaking into two sealed components in a working environment which was not dust-free and humidity controlled.

During this installation, the wrong size and type of O-ring was used, which subsequently failed and leaked. This was the fourth error.

*An unsuccessful effort was made to find out exactly how this error was made. Since technical data procedures were not used, it was impossible to reconstruct exactly who did what and when. One thing is sure; if the accumulator ever was recharged, the technician failed to close the Schraeder valve, or someone subsequently reopened the Schraeder valve, because the valve was open when the accumulator failed, i.e., it caused the failure.

During efforts to correct this leak, it was noted that a 1/8-inch piece of this O-ring was missing. When it could not be found, it then became necessary to reject this entire hydraulic control package. GD/A logistics could not supply another control package so soon after the first request. Therefore, the package on missile 64E was cannibalized. This was the fifth error.

Meanwhile, the sustainer turbopump gears were rotated three times in 4 days and were not represerved until 6 days after first rotation. This was the sixth error since the maximum delay should have been 72 hours.

Equipment Affected

LR105NA-5 sustainer engine; 551751 hydraulic control package; 453902 turbopump assembly.

Job Operation/Task

Missile systems checkout, T.O. 21-SM65E-CL-7-3

Problem Criticality	Problem Type
Major	Safety; Personnel Selection and Manning; Organizational Controls; Training

System Implications

During an investigation of errors of this variety, there are invariably a great number of excuses offered by personnel involved. Many of these employ a misleading kind of false logic that it is important to dispel.

One of the major questions to be investigated concerns why the approved technical data were not followed. One frequent reply is, "Oh, didn't you know? No one ever uses the tech data." This is not true. The approved technical data are often used, and when they are there are invariably fewer mistakes made. However, even if it were true that no one ever uses the approved technical data procedures, this would not justify the practice and it would still require some explanation.

Another answer often given is, "Sometimes we don't have the latest technical data." True, but immaterial. They had the latest technical data available this time.

A third example of false logic is, "I looked at that T.O. once, and it called the (such-and-such) a (so-and-so)." Just because the technical data did not conform to local jargon, or once contained a mistake, does not mean the entire book is wrong. If technicians find errors in the technical data, they should attempt to have it corrected. They should never use it as an excuse to stop using it altogether.

Top-caliber airline flight and maintenance personnel have used and valued checklists and other technical data for many years as a tool for improving their own personal performance reliability. The most dependable civilian and military missile maintenance personnel have developed the same attitudes. There are undoubtedly many trivial reasons why some individuals do not choose to follow the approved technical data. Disregarding these reasons, such technicians should immediately be recycled through an appropriate type of reliability motivational training, ORT, or, in extreme cases, be removed from this career field.

Recommended Corrective Action

The ability and inclination to follow the established procedures should be made a major criterion of both personnel certification and proficiency evaluations. Uncertified technicians should never be permitted to perform critical maintenance tasks except under close supervision. Failure to follow the approved procedures should invariably require corrective training or transfer to a less critical career field.

Action Taken

Incident Report Number and Date	Disposition
D/D 5751R 26 January 1962	7 February 1962: PSRB assigned to SAC MAB-2 Site Commander for corrective action.

SAFETY PROBLEM NO. 5
(HUMAN FACTORS PROBLEM NO. 98)

STANDING ON THRUST CHAMBERS

Incidents

On 19 separate occasions, personnel were observed standing, sitting, or jumping on booster or sustainer thrust chambers. In most cases, this recourse was taken because no work platform provisions had been made for access to certain task areas, i.e., certain tasks were difficult if not impossible to perform satisfactorily without standing on the thrust chambers.

Equipment Affected

Booster and sustainer engine thrust chambers.

Job Operations/Tasks

1. Placing missile in stretch at launch site
2. Removing missile from stretch at launch site
3. Installing upper riseoff disconnect panel at MAMS
4. Aft rail alignment and inching operation at launch site

Problem Criticality

Major

Problem Type

Safety; Potential Engine Failure; Provisioning Deficiency; Training; Organizational Control

System Implications

The discovery and correction of this kind of major oversight is an example of the important contribution of operational systems testing to the operational reliability of the weapon system. It is difficult to understand how such oversights could get through to the activation stage, but they do in spite of task analysis and other efforts which could be expected to discover and correct such conditions much earlier in the design cycle. Since these were not "Rocketdyne tasks," Rocketdyne does not have access to the Task Analysis Work Sheets that would be necessary for determining the exact reasons for this oversight. One reason may be that task analysts sometimes are forced by time restrictions to hurry to complete a particular study. They may merely list part numbers of access platforms without actually determining if these platforms do support the human task requirements.

There have been several false rumors regarding this practice of standing on thrust chambers. At one missile base, it was reputed to be "okay with Rocketdyne because these engines are rugged and are built to take much greater loads than a mere man." Rocketdyne's position is that such "ruggedness" would constitute extremely poor design; the engine thrust chambers are built to handle large combustion pressures and thrust loads, but they are not built to be maintenance platforms.

At another base, it was reported that standing on thrust chambers was "okay with Rocketdyne if you take your shoes off." Admittendly, stocking feet are less likely to scratch and dent fuel tubes than GI shoes, but the man's weight can still cause tube deformations and overstressed brazing.

At another site on the same base, it was alleged and erroneously supported in some instances by a misinformed Rocketdyne field service representative that standing on thrust chambers is "okay with Rocketdyne if you put the red shipping covers on first." Since the red shipping covers were not designed for this purpose, the degree of protection afforded when used in this way is somewhat unpredictable, and this practice therefore is not condoned by R/NAA. The widespread prevalence of misinformation is significant for understanding the complexity of corrective measures.*

Recommended Corrective Action

1. Disseminate correct information concerning the necessity of staying off thrust chambers.
2. Provide additional maintenance platforms, as required, for access to stretch hooks and upper riseoff disconnect panels and any other tasks that may later be found to contribute to this problem.
3. Strict enforcement by integrating contractor and customer of Rocketdyne recommendations concerning not standing or walking on thrust chambers.

Action Taken

Incident Report Number and Date	Disposition
D/D 430R, 5 July 1961	23 August 1961: PSRB approved D/D 430R and sent to SAC and EDRB
D/D 1134R, 4 September 1961	September 1961 issue of R/NAA Service News urges personnel to stay off thrust chambers at all times, and explains why.
D/D 2018R 18 September 1961	6 October 1961: PSRB approved D/D 2018R, assigned to EDRB, SAC, and AF Safety for action.

Incident Report Number and Date	Disposition
D/D 2214R, 2 October 1961	11 October 1961: R/NAA policy statement: "Personnel shall not stand or walk on any part of the thrust chamber assembly or on the red shipping covers."
D/D 2596R, 13 October 1961	18 October 1961: PSRB approved Par 24, assigned to EDRB.
D/D 2204, 2 October 1961	25 October 1961: PSRB added D/D 2596R to Par 24.
D/D 2251, 3 October 1961	16 November 1961: EDRB approved GD/A Par 39; CRL 9 to San Diego.
D/D 2300, 4 October 1961	22 November 1961: EDRB approved R/NAA Par 24; authorized CRL.
D/D 2388, 10 October 1961	26 November 1961: EDRB rejected R/NAA Par 24, because problem will be resolved by workstand requested by CRL 9.
D/D 2419, 11 October 1961	28 December 1961: PSRB assigned 544R to MAB Site Commander
D/D 2420, 11 October 1961	12 January 1962: MAB Site Commander reported that corrective action (undescribed) has been taken.
D/D 2439, 11 October 1961	4 April 1962: PSRB rejected 5940R; not a new problem.
D/D 2440, 11 October 1961	8 May 1962: R/NAA PSS coordinator cancelled D/D 5964R due to unwillingness of PSRB to process 5940R.
D/D 3006, 16 October 1961	25 July 1962: PSRB assigned 6037R to OSTF-1 Site Commander.
D/D 2008, 18 September 1961	August 1962: Article entitled "Thrust Chambers are Not Work Platforms" appeared in the July-August 1962 issue of Rocketdyne Service News, pages 4 and 5.
PCS A-651-1462, 13 November 1961	
GD/A Par 38, 8 November 1961	
D/D 5444R, 1 December 1961	
D/D 5940R, 28 March 1962	
D/D 5964, 8 February 1962	
D/D 6037R, 18 June 1962	

SAFETY PROBLEM NO. 6
(HUMAN FACTORS PROBLEM NO. 302)

INSTALLING THROAT PLUGS

Incident

The MET/M was observed trying to install the booster engine thrust chamber throat plug, a task not considered hazardous if correctly performed. However, the assistant usually assigned was not on hand and the MET/M elected to proceed unassisted. The work stands were not in position around the thrust chamber, either. After several minutes of unsuccessful pushing upon the plug, the MET/M climbed into the thrust chamber and attempted to kick it into position in the throat. The kick only succeeded in overcoming his own coefficient of sliding friction and he half slid, half rolled to the end of the thrust chamber, where he was barely able to catch the fuel return manifold with his fingers and save himself from falling. After several repetitions of this near accident, he pulled the throat plug out to investigate the cause of his difficulties and found that the tire was not completely deflated. Upon proper deflation, the plug was installed without excessive difficulty.

Equipment Affected

LR89NA-5 booster engine; 903404-11 throat plug in the G3080 plates and plugs kit

Job Operation/Task

Checklist AP62-0133, Section 36, Booster Engine System Checkout (11 July 1962)

Problem Criticality	Problem Type
Major	Safety; Training; Job Environment

System Implications

If the MET/M had had a helper, or if the work stands had been in position, the kicking of the throat plug could possibly have been done without hazard to himself. However, the nickle thrust chamber fuel tubes are easily scratched or dented. The MET/M should know better than to kick anything in proximity to a thrust chamber.

Recommended Corrective Action

Operational Readiness Training could be modified to place greater emphasis upon team work, the importance of work stands, and a thorough compliance with procedural details (as opposed to presuming that certain steps were previously accomplished by someone else).

Action Taken

Incident Report Number and Date	Disposition
D/D 6315R 26 October 1962	26 November 1962: PSRB assigned to Capt. Spowart, BSD, MAB-2

SAFETY PROBLEM NO. 7
(HUMAN FACTORS PROBLEM NO. 154)

CLEANING WITH TRICHLOROETHYLENE

Incidents

The MET/M was observed cleaning inside the missile thrust section using rags and trichloroethylene solvent. He did not, however, use gloves, a face shield, or breathing apparatus. Several months later, another MET/M was observed cleaning lubricant from the engine thrust chamber throat using rags and trichloroethylene, but without gloves.

Job Operations/Tasks

1. Ready State B, Securing from residual fuel drain, T.O. 21-SM65E-CL-15-2, Section 22
2. Booster Engine System Checkout, removing thrust chamber throat plug, AP62-0133, Section 36, 11 July 1962

Problem Criticality	Problem Type
Major	Safety; Organizational Controls; Training

System Implications

If personnel were this negligent concerning critical safety precautions while they were being watched by a human factors observer, it may be supposed that a great deal more of this is going on when no one is looking. This means that merely designing good safety equipment and safe procedures for doing hazardous tasks is not enough:

1. The safety equipment must be made conveniently available. (In the incident cited above, gloves were not worn because they were not conveniently available from the nearest tool crib. They had to be obtained from base supply.)

2. Personnel must know what the dangers are in their tasks and understand how their technical data and safety equipment protect them when they use them properly. Case histories of recent accident victims can be used to "bring the hazard home." Refresher training may be appropriate when a technician is observed deviating from safe practices; frequent deviation must be cause for disciplinary action, not just for the sake of the deviant individual but largely to encourage and support those who are conscientiously trying to do their jobs correctly.

3. Standard operating procedures must be revised to require and support sound safety practices, and must undergo further revisions and reorganizations as necessary until real success is achieved, i.e., individual technicians identify with safety needs, voluntarily defend them, and habitually employ them.

Recommended Corrective Action

Safety equipment must be made more readily available. Organizational controls to support safety requirements in the technical data must be revised as necessary. Personnel must be trained to employ safe cleaning practices when using trichloroethylene.

Action Taken

Incident Report Number and Date	Disposition
D/D 2120R, 25 September 1961 D/D 6213R, 9 August 1962	6 October 1961: PSRB assigned to TDRB 9 October 1961: TDRB holding for investigation 12 October 1961: TDRB rejected; technical data contains proper safety information; considered a training and organizational control problem; sent to SAC for incorporation in SOP, ORT February 1962: The necessity of observing proper safety precautions while using toxic solvents in confined areas was re-emphasized by article on page 4 of R/NAA Service News. 10 September 1962: PSRB assigned 6213R to Capt. Spowart, BSD, MAB-2, with information copies to 6595th Safety.

SAFETY PROBLEM NO. 8
(HUMAN FACTORS PROBLEM NO. 231)

PREGIMBALING PRECAUTIONS

Incident

A postmaintenance verification of sustainer engine gimbaling had just begun when a loud clatter and banging was heard coming from the missile thrust section. Operations were quickly aborted and a man entered the thrust section to see what was the matter. Six steel pressure plugs and caps were found in various parts of the missile thrust section. A mechanic admitted having left these on top of the No. 2 booster engine several hours previously. The missile thrust section interior apparently had not been properly policed before gimbaling operations were allowed to begin.

Equipment Affected

LR105NA-5 sustainer engine

Problem Criticality

Major

Problem Type

Safety; Organizational Controls; Training

System Implications

Gimbal vibrations undoubtedly caused the caps and plugs to roll off the B-2 engine and bounce through the thrust section envelope. Extensive damage could have resulted had the parts become trapped or wedged in any of the numerous areas of small clearances, or in convolutions of flexible ducts or bellows, during the gimbaling.

Both the technical data involved and local SOP require policing of the thrust section before gimbaling the engines. However, some of the personnel involved in this incident did not seem to know the purpose for this.

Recommended Corrective Action

Expose personnel during ORT to information concerning why it is important to police thoroughly before gimbaling the engine. Employ organizational controls to support SOP and technical data requirements.

Action Taken

Incident Report Number and Date	Disposition
D/D 5752R 26 January 1962	7 February 1962: PSRB assigned to MAB-2 Site Commander for action.

SAFETY PROBLEM NO. 9
(HUMAN FACTORS PROBLEM NO. 148)

FUEL FUMES IN BOATTAIL

Incident

While the MET/M was connecting fuel drain hoses inside the missile thrust section, fuel leaked out of joints and fittings in the drain spider. The concentration of fuel fumes became so heavy that the MET/M was nearly asphyxiated. The human factors observer helped him to exit safely.

Equipment Affected

Fuel drain kit, part number unknown.

Job Operation/Task

Ready State B, Vertical drain residual fuel, T.O. 21-SM65E-CL-15-2, Section 22

Problem Criticality

Major

Problem Type

Safety; Provisioning; Equipment Design; Job Environment

System Implications

The drain kit used was not the operational equipment. Later tests showed that less fuel will be spilled using the operational configuration. However, it is still fairly easy to spill enough fuel to make the boattail atmosphere noxious.

The cost of providing a completely goofproof drain kit is probably excessive. However, an existing thrust section heater has a blower unit which (if it could be used independently of the heater) might fulfill the recommended corrective action and maintain a satisfactory breathing atmosphere.

Recommended Corrective Action

Install either a blower or an exhaust fan for elimination of fuel fumes inside the missile thrust section during fuel draining procedures.

Action Taken

Incident Report Number and Date	Disposition
D/D 2042R 20 September 1961	11 October 1961: PSRB approved and assigned to AF Safety. 29 November 1961: Unspecified corrective action completed.

SAFETY PROBLEM NO. 10
(HUMAN FACTORS PROBLEM NO. 283)

CROWDING IN MISSILE THRUST SECTION

Incidents

On three different occasions the human factors observers reported excessively crowded work conditions inside the missile thrust section. There is enough room for 2 or 3 to work efficiently, but from 4 to 15 people have been seen inside the Atlas E and F series missile thrust sections at VAFB OSTF sites on approximately 20 different occasions. Incidents involving minor to moderate crowding and minor to moderate loss of efficiency were not reported. Incidents were reported when the crowding was severe, or when the crowding caused critical safety hazards, i.e., during installation and removal of live pyrotechnics and hypergolics where safety exit routes were obstructed.

Job Operations/Tasks

Checklist AP62-0132, Section 68 and 40, Ready State A Training and Missile Securing from EWO, 4 June 1962.

Problem Criticality

Major

Problem Type

Safety; Job Environment; Organizational Control

System Implication

Control action on this problem conflicts with other legitimate goals, e.g., training certification and quality assurance. Task manning in the thrust section usually involves one technician (to do the work), one engineer (who is responsible for the missile until it is sold and therefore wants to see everything that is done), and one inspector (because he has to certify that the job was done and was done properly). Add a human factors observer to certify the technician, and it gets worse. Some tasks require or can be expedited by using more than one technician. And sometimes (for new procedures), a publications representative needs to be present to verify or validate the technical data. Add to this the fact (established by personal interview) that many of the people who are responsible for task scheduling do not know what tasks are performed inside the missile thrust section, and the observed results are then understandable: two and sometimes three tasks are scheduled for simultaneous accomplishment in the boattail section, each with a crew of three to eight people.

Recommended Corrective Action

Be certain that task schedulers know which tasks are performed inside the missile thrust section, and add controls to prevent scheduling more than one of these tasks at a time. Hazardous tasks, e.g., removal and installation of live pyrotechnics and hypergolics should not be "speeded up" by assigning extra helpers, but should be done with as few people as possible.

Action Taken

Incident Report Number and Date	Disposition
D/D 6124R 5 July 1962	25 July 1962: PSRB assigned 6124, 6126, and 6142 to OSRF-1 Site Commander with information copies to 6595th Test Wing Safety Group
D/D 6126R 5 July 1962	
D/D 6142R 11 July 1962	

SAFETY PROBLEM NO. 11
(HUMAN FACTORS PROBLEM NO. 223)

HUMAN PACK HORSE

Incident

At the time the No. 1 vernier engine was to be installed, the overhead crane was down for maintenance. Rather than wait, a husky MET/M picked up the engine and hand carried it up the ramps and ladders to the top of the missile.

Job Operation/Task

T.O. 21-SM65E-CL-3-3, Section 12, Vernier engine installation, 15 December 1961

Problem Criticality	Problem Type
Major	Safety; Organizational Controls; Training

System Implications

With the gimbal actuators, flight fairings, and other auxiliary equipment installed, this engine weighed approximately 95 pounds and required both hands. Carrying a bulky 95 pound piece of hardware up an 8-foot ladder in this manner is difficult and dangerous. The airman demonstrated initiative and equipoise. But he subjected the engine to unnecessary risks of bumping or dropping, and he jeopardized his own and the missile's safety. He also carried the engine by propellant lines instead of using proper hoisting points.

Recommended Corrective Action

If operations could not wait for the overhead crane to be repaired, a suitable alternate method (e.g., a block-and-tackle, two-sheave hoist), should have been substituted.

Action Taken

Incident Report Number and Date	Disposition
D/D 5621R 5 January 1962 D/D 5622R 5 January 1962	10 January 1962: PSRB assigned action to MAB-2 Site Commander 27 January 1962: Brought to the attention of GD/A test supervision, and to SAC Lt. Col. Sullivan 6 February 1962: Action considered complete, D/D's closed. NOTE: Problem recurred on "F" series missiles on 16 October 1962 during OSTF-2 test program. (See Problem F-51 in Rocketdyne report R-3569-9, 15 December 1962.)

SAFETY PROBLEM NO. 12
(HUMAN FACTORS PROBLEM NO. 285)

CHECKLIST DEVIATIONS

Incidents

The checklist enumerated the safety equipment which was to be worn during the task, but some technicians did not wear any. The checklist required exclusion of all unauthorized and unessential persons from the area for the duration of the intense hazards, but they were permitted to remain. The checklist stated the correct tools to be used; unsatisfactory substitutes were made. The checklist step sequence and task manning were totally ignored and were varied to suit the whims of the test engineer.

Job Operations/Tasks

Checklist AP62-0132, Section 40, Missile Securing from EWO, particularly the removal of pyrotechnics and hypergolics; and Section 68, Ready State "A" Training, particularly the installation of pyrotechnics and hypergolics.

Problem Criticality	Problem Type
Major	Safety; Job Environment; Organizational Controls; Training

System Implication

There has been a sprinkling of problems throughout the OSTF-1 test program which was caused by not following the technical data requirements (e.g., problems 154, 230, 274, and 288). The four D/Ds which reported the above incidents could have been analyzed separately, but by grouping them a very significant relationship may be seen. As the average beginning technician gains in proficiency, job knowledge, and confidence, he seems to enter a stage that is somewhat analogous to some adolescents (as far as the types of behavior control problems that occur). Some teenagers tend to resent parental authority. They may try to find fault with the parent authority. They may try to find fault with the parents' directions, standards, and methods. At times, they may attempt to function independently of their parents in areas where they are not yet sufficiently wise or experienced to do so successfully. And they may quickly (thoughtlessly) use or incorporate group norms which condone rebellious or defiant attitudes or deeds toward parents, teachers, policemen, or other persons in positions of authority. In much the same way, some technicians approaching a medium skill or proficiency level begin to resent the technical data, nitpick it, try to get along without it when they cannot or should not, and they react negatively and somewhat rebelliously toward every requirement that seems in the least bit unnecessary. Also, social support is exchanged with other technicians in the same stage of development so that the process of growing out of this stage appears to be retarded or stopped.

Recommended Corrective Action

1. Emphasis should be placed on the mature technician who has developed respect for the technical data in relation to the need for ultra-high reliability and personnel performance standards.

2. Both the civilian and military organizations with this problem could develop reliability orientation lectures, films, posters, and brochures which would include material to help the technicians to counteract or gain insight into this type of behavior.

3. It will also be necessary to provide organizational control reinforcement of appropriate reactions and discouragement of the irresponsible reactions and attitudes toward technical data requirements.

Action Taken

Incident Report Number and Date	Disposition
D/D 6126R 5 July 1962 D/D 6143R 10 July 1962 D/D 6144R 10 July 1962 D/D 6145R 10 July 1962	25 July 1962: all four D/D's were assigned by the PSRB to the OSTF-1 Site Commander, with information copies to 6595th Safety.

SAFETY PROBLEM NO. 13
(HUMAN FACTORS PROBLEM NO. 227)

DROPPING SOLID PROPELLANT GAS GENERATORS

Incident

The No. 1 MET/M attempted to hand the B-1 SPGG through the turbine spinner access door to his helper outside the missile thrust section. (He should have handed it through the boattail.) He bumped the SPGG against the turbopump and dropped it.

Equipment Affected

Booster engine SPGG, part No. 650982-21.

Job Operation/Task

T.O. 21-SM65E-CL-21-2, Section 1, 24 November 1961, Missile Removal; 20.63/50009 Explosive Assemblies Removal.

Problem Criticality	Problem Type
Major	Safety; Training

System Implications

Inert igniters, initiators and SPGG's were used during the test run, and so nothing was seriously damaged. However, if live SPGG's had been used, it is probable that the propellant grain would have been clipped or fractured and thereby ruined. Also, nearby components could have been badly dented or broken. Apparently, during Operational Readiness Training, neither MET/M had been taught the proper routing for handling SPGG's into and out of the missile thrust section.

Recommended Corrective Action

Train MET/M's in the proper handling of SPGG's, i.e., never to attempt handing them through the turbine spinner access door, but to hand them through the boattail.

Action Taken

Incident Report Number and Date	Disposition
D/D 5737R 9 January 1962	24 January 1962: PSRB assigned action to AF Site Safety 5 April 1962: Action also assigned to SAC, Capt. Smith.

SAFETY PROBLEM NO. 14*
(HUMAN FACTORS PROBLEM NO. 57)

ADAPTER IDENTIFICATION

Incidents

Many difficulties were encountered by operators attempting to use the various checkout, servicing, and maintenance adapter sets because of inadequate part and location identification:

1. Some adapters are not identified by part number, or by a complete part number.
2. Many are standard AN or MS fittings and carry no identification which would make them identifiable as a part of a kit.
3. None is color coded to indicate special use.
4. Storage pockets do not have identification numbers.
5. Kit contents decals list only the part numbers and quantities, and do not contain any size data or descriptive nomenclature.

The specific problems caused by these identification deficiencies are:

1. Quickly finding the adapter wanted is moderately difficult. The often untrained and unskilled worker helping the skilled MEM (who is inside the missile thrust section) will make several trips with wrong parts before bringing as many as he can carry so the skilled man may select.
2. The desired adapter is frequently missing. With more than a dozen sets to choose from, the adapters are often returned to the wrong set, or even put back in AF stock.

*NOTE: This problem is not classified as a primary safety problem but is included in this report because several of the other safety problem case studies make reference to it.

3. When adapters are missing it is extremely difficult to find them again.

Equipment Affected

Adapter sets 9010364-11, 9014490, 9014475, and adapters in other AGE, such as the G3004 flow tester.

Job Operations/Tasks

Engines flush and purge, servicing, checkout, and turbopump preservation

Problem Criticality

Minor, moderate, and major

Problem Type

Equipment Design (operability; functional deficiency)

System Implications

Four effects have been noted so far.

1. Unpredictable maintenance time: the actual time required to perform these operations becomes a function of the condition of the adapter kits, i.e., how long it takes to locate the needed adapters. Normal maintenance controls suffer.

2. Potential hardware damage: Several mechanics will be keeping an improvised facsimile of the most frequently used adapters in their tool boxes. Several of the safety features of the approved adapters may be lost (controlled pressure drop, relief valves, contamination control, protective packaging of threads, flares, etc.).

3. Technician irritation and frustration: The more conscientious the technician, the more this problem will tend to irritate him.

4. Deviations from approved procedures: A growing use of improvised adapters leads to improvised procedures and the related problems.

Recommended Corrective Action

1. Permanently identify all adapters with their complete part numbers and the part number of the kit to which it belongs.

2. Identify kit storage pockets with the part number of the adapter that belongs in it.

3. Provide separate storage pockets or compartments for each adapter in the few cases where this has not already been done.

4. Color code adapters intended for special use, wherever feasible, and group adapters (i.e., store all oxidizer system adapters together, separated from electrical adapters, fuel and hydraulic system adapters, etc.).

5. Revise kit contents decals to include quantity, name, complete part number (or part number and size), and special use (if applicable) for each item.

Action Taken

Incident Report Number and Date	Disposition
VAFB OSTF Training Static Evaluation, Items 3, 4, and 9	R/NAA will consider recommendations for future design.
VAFB OSTF Training D/D T-12R, June 1961	None. D/D's written by observers in training were not processed by the PSRB.
D/D 5601R, 28 December 1961	10 January 1962. PSRB assigned to EDRB and R/NAA 1 February 1962. EDRB rejected. "If MEM doesn't know his adapters, he shouldn't be an MEM."
D/D 5881R, 15 February 1962	28 February 1962. PSRB rejected.

NOTE: Adapter kits manufactured by other firms have had similar problems.

SAFETY PROBLEM NO. 15
(HUMAN FACTORS PROBLEM NO. 221)

HOISTING VERNIER ENGINE MAINTENANCE PLATFORM

Incident

Four men were observed struggling with the combination maintenance platform and access ladder to the No. 1 vernier engine. They were trying to lift it into the proper position for use. The ladder section was approximately 8-feet long, and the platform section at the top was about 5-feet across, constructed of aluminum and complete with hand rails. It was top heavy and awkward to handle in this manner. One slip by one man could have resulted in a punctured missile fuel tank.

Equipment Affected

Work platform set 27-97020-1

Job Operation/Task

Task 75002/121.1A, Install Maintenance Platforms, T.O. 21-SM65E-CL-3-3.

Problem Criticality	Problem Type
Major	Safety; AGE Provisioning

System Implications

A punctured fuel tank could result in a bulkhead reversal, requiring additional major repairs and missile out-of-commission time beyond the repair of the punctured tank. These difficulties would tend to discourage personnel from using the platform at all. (See Human Factors Problem No. 216 for a related problem.)

Recommended Corrective Action

A special sling could be provisioned that would enable the overhead crane to be used to hoist and position the platform.

Action Taken

Incident Report Number and Date	Disposition
D/D 5619R 5 January 1962	10 January 1962: PSRB assigned action to EDRB 1 February 1962: CRL 46 submitted for approval 14 February 1962: EDRB approved and forwarded CRL 46 to ECAG at Norton AFB. (Date of action unknown): ECAG placed on hold. Later approval depends upon availability of funds. ECAG control No. 2238. (Information received 4 January 1963.)

SAFETY PROBLEM NO. 16
(HUMAN FACTORS PROBLEM NO. 16)

OPERATOR FOOTING ON FLUSHING STAND

Incidents

Very insecure footing for the MET/M made it difficult to connect flush and purge hoses to the engine safely while it was installed on the flushing and maintenance stand. The only places to stand were on the round frame members which are often slippery and never really safe. The MET/M had to make most connections using one hand, and holding on with the other. When a two-handed task was encountered, it was usually performed from the top of a tall stepladder, leaning awkardly toward the engine. A helper must hold the ladder firmly or it will tip over. The problems were particularly acute when the stand was pumped to the vertical position.

Equipment Affected

Rocket Engine Flushing and Maintenance Stand, Air Logistics Part No. 107175

Job Operations/Tasks

(1) Flush and Purge Booster Engine, T.O. 2K-LR89-12-3; (2) Flush and Purge Sustainer Engine, T.O. 2K-LR105-12-3

Problem Criticality	Problem Type
Major	Safety; Job environment

System Implications

This is a standard flushing and maintenance stand for all liquid-propellant rocket engines. Therefore, the obvious welding-on of work platforms is not appropriate since the universal capabilities would be compromised.

Recommended Corrective Action

A special work platform which can be temporarily clamped onto the flushing and maintenance stand should be designed and provided for Atlas operational sites.

Action Taken

Incident Report Number and Date	Disposition
Van Nuys EMA Testing S.E. No. 6, January 1961	February 1961: R/NAA engineering concurrence with EMA recommendations; AFBSD queried. May 1961: STL/AFBSD indicated approval with formal request for proposal to follow after end of fiscal year. September 1961: Request for design proposal received and design layout begun. October 1961: Drawing 9014994 completed, ready for customer review and approval. November 1961: All work stopped; 576th-SMS maintenance shops fabricated their own maintenance stand; found it entirely adequate, and other using activities may copy it.

SAFETY PROBLEM NO. 17
(HUMAN FACTORS PROBLEM NO. 60)

SHOCK HAZARD

Incident

On several occasions, the mechanic mistook an "off" condition of the MAIN POWER ON indicating light to mean that 440-volt power was off the G2000 service unit. Since this light was on the 110-volt control power circuit, it actually functioned as an "and-gate indicator." An off condition merely meant that at least one of five circuit-completing functions had not taken place. In each case, the task decisions which resulted from this interpretive error were inappropriate for the situation. Although none of these incidents resulted in injury to the personnel, the possibility existed.

Equipment Affected

G2000 Rocket Engine Lubricating-Purging Service Unit AF/M46M-1

Problem Criticality	Program Type
Minor	Safety Maintainability

System Implications

Prevention of major ambiguities in control panel nomenclature deserves more attention during the earliest stages of equipment design, and during any subsequent major configuration changes which affect the function or meaning of controls and indicators. This task can be performed by a procedure resembling design review, but performed by one or more people who have: (1) a systems perspective emphasizing the use to be made of the equipment, (2) a thorough understanding of the internal circuitry and functioning of the unit in question, (3) a knowledge of human engineering design principles, and (4) experience with human error prediction, investigation, and control for operational systems.

Recommended Corrective Action

The cost would not justify changes to existing units. Therefore, it was recommended that information be made available to customer maintenance personnel concerning the actual meaning of this indicator light. For future designs, similar lights should be identified CONTROL POWER ON, and additional lights added to indicate 440-V POWER APPLIED and MAIN POWER ON.

Action Taken

Incident Report Number and Date	Disposition
Van Nuys EMA Testing, BE5, May 1961	June 1961: Article prepared for Rocketdyne Service News; nomenclature and indicator light changes will be considered for future design.
VAFB OSTF Observer Training D/D T-4R (not processed because it merely duplicated EMA data)	August 1961: Service News article appeared, Vol. 2, No. 7, page 5, "Main Power Indicator Lights".

SAFETY PROBLEM NO. 18
(HUMAN FACTORS PROBLEM NO. 71)

PLACARDING OF OPERATING VOLTAGE

Incidents

During a human engineering static evaluation of propulsion system operational AGE, it was noted that the operating voltages of both circuit breakers on the G2000 service unit were not placarded. During later operational testing at the Van Nuys EMA, it was noted that this lack of placarding contributed to operator error and confusion in following the job manual procedures.

Job Operations/Tasks

1. Preparation of G2000 for Servicing Operations
2. Securing of G2000

Problem Criticality	Problem Type
Minor	Safety

System Implications

Usual safety practice requires the placarding of the operating voltage of all circuit breakers in a room or on a piece of equipment if the operating voltage of any one of them exceeds 200 volts. On this service unit there was no identification marking of the operating voltage on either the 110- or 440-volt circuit breakers. For operators with recent experience on this equipment, this lack of identification is no problem. However, when a period of time elapses between receipt of training and actual use of the equipment, the operator can make minor procedural errors such as turning the wrong circuit breaker off or on.

Recommended Corrective Action

Stencil or otherwise placard the operating voltage in a conspicuous place on the exterior of the circuit breakers.

Action Taken

Incident Report Number and Date	Disposition
VAFB OSTF Observer Training Static Evaluation Item No. 11, January 1961	June 1961: The recommended corrective action will be incorporated in future designs. In existing units this is not a mandatory fix; R/NAA is therefore reluctant to propose any retrofit action out of consideration for current Air Force budgetary restrictions. The using activities are capable of accomplishing this simple fix without contractor directions. Rocketdyne reports R-3520 and R-2831-8 informed the Air Force of this need. June 1962: Placarding was not required on new designs G2016 solvent pumping unit and G2017 oil pumping unit because all circuits are 110-volt.

SAFETY PROBLEM NO. 19
(HUMAN FACTORS PROBLEM NO. 85)

SLIPPERY STEP

Incident

A human factors observer, performing a static evaluation of the G2000 service unit, stood on the step to check accessibility to the servicing points on top of the unit. The step was found to be so slippery that it would have been difficult to maintain secure footing during actual servicing tasks.

Equipment Affected

G2000 Rocket engine lubricating-purging service unit AF/M46M-1.

Job Operation/Task

Servicing the G2000

Problem Criticality	Problem Type
Minor	Safety

System Implications

This step was added by TCTO 35E22-2-5-502, generated from MCR9313-105 and Modification Instruction R-1079-70. This change was still in the design stage during the OSTF EMA test program on the G2000. A prototype could have been installed and tested on the EMA unit prior to the end of the program, and the problem detected before release of modification instructions and kits. Instead, most of the delivered units were modified according to the modification instructions before the problem became known.

Recommended Corrective Action

Application of Armortread nonskid paint to the step.

Action Taken

Incident Report Number and Date	Disposition
R/NAA VAFB OSTF Observer-Training Static Evaluation Item No. 1, January 1961	19 May 1961: Corrective action cannot be accomplished by revision to modification instructions because all units are already modified. August 1961: Service News article requested to inform field personnel of hazard and how to correct it. November 1961: Service News article request refused because TCTO will be issued (paint can be applied by direction of TCTO). January 1963: TCTO completed, containing directions for applying the nonskid paint to the step (Figure 5, Detail 9). 4 January 1963: Service News article again requested to inform field personnel of difference between mod instruction and TCTO, and to recommend addition of nonskid paint to step by local maintenance activities. 11 January 1963: Service News article request approved. Article to appear in March-April 1963 edition.

SAFETY PROBLEM NO. 20
(HUMAN FACTORS PROBLEM NO. 86)

NONPLACARDED DANGER AREAS

Incident

During a human engineering static evaluation of propulsion system operational AGE, it was noted that four danger areas on two pieces of equipment were not appropriately placarded.

1. The high-pressure pneumatic supply inlet fitting on the G3077 test stand (1500 to 3200 psig operating pressure): The existing placard was inconspicuous and only indirectly conveyed the information that a pressure hazard could exist.
2. Hose reel No. 5 on the G2000 service unit (also 1500 to 3200 psig operating pressure): The same deficiencies were noted, as above, in existing placards.
3. The solvent tank filler cap on the G2000 service unit: None of the placarding warned the operator not to remove the cap while the tank was pressurized.
4. The main power cable (440 VAC) on the G2000: All placarding was satisfactory except that it was located inside the access door to hose reels instead of inside the access door to the power cable.

Equipment Affected

1. G2000 rocket engine lubricating-purging service unit AF/M46M-1
2. G3077 electrical-pneumatic systems test stand AF/E47T-1

Problem Criticality

Minor

Problem Type

Safety

System Implications

Less experienced maintenance personnel, who are not yet completely familiar with the equipment, can get hurt. A few such accidents or near accidents can earn a negative reputation for an item of equipment, and it often becomes a negative prestige factor for technicians to be assigned to maintenance functions on it. This, in turn, produces a degradation of maintenance standards and progressively increases the severity of other man-machine problems on this equipment. This example serves to emphasize the importance of early human factors evaluations of equipment design.

Recommended Corrective Action

Correct the noted placarding deficiencies.

Action Taken

Incident Report Number and Date	Disposition
R/NAA VAFB OSTF Observer-Training Static Evaluation Item No. 2, January 1961	May 1961: Placarding requirements will be more closely studied for future designs.

Incident Report Number and Date	Disposition
	February 1962: A safety interlock feature and an indicator are an integral part of the 9420-W-40C solvent tank filler cap, superseding present G2000 solvent tank caps for future procurement. The new caps automatically lock in place when tank is pressurized. June 1962: Stencilled lettering "CAUTION, DO NOT REMOVE PRESSURE CAP WHILE UNIT IS OPERATING" added to new designs for G2016 solvent pumping unit and G2017 oil pumping unit adjacent to appropriate caps.

SAFETY PROBLEM NO. 21
(HUMAN FACTORS PROBLEM NO. 88)

SHARP CORNERS

Incident

During a human engineering static evaluation of propulsion system operational AGE, sharp corners were noted on two items. Bumping these could injure or annoy engine maintenance personnel or damage other equipment.

Equipment Affected

1. G3080 Booster Engine Checkout and Maintenance Plate and Plug Kit KMU-15/E
2. G3087 Sustainer Engine Checkout and Maintenance Plate and Plug Kit KMU-16/E

Problem Criticality	Problem Type
Minor	Safety

System Implications

None

Recommended Corrective Action

Future designs of equipment this large should incorporate rounded corners. If numerous instances of damage or injury are reported, rubber bumpers could be cemented onto existing units.

Action Taken

Incident Report Number and Date	Disposition
VAFB OSTF Observer Training Static Evaluation Item No. 7, January 1961	May 1961: Rounded corners will be considered for future design. June 1962: Rounded corners were used on new designs G2016 and G2017

SAFETY PROBLEM NO. 22
(HUMAN FACTORS PROBLEM NO. 121)

COMMUNICATION NEEDED

Incident

The MET/M entered the missile thrust section and connected drain hoses for draining residual fuel. He did not communicate with the missile pressurization crew before connecting the drain hoses. The crew was temporarily preoccupied with other things and almost failed to notice the dropping fuel tank pressure until too late to prevent equipment damage and personnel injuries.

Job Operation/Task

Ready State B, T.O. 21-SM65E-CL-15-2, 11 November 1961, Section 22, Vertical Drain Residual Fuel

Problem Criticality

Major

Problem Type

Safety; Technical Data; Organization Controls

System Implications

Many thousands of dollars have been spent designing, building, and refining the launch site communications system. However, it still must be used at crucial points or it cannot prevent the well-known calamities that result from uncoordinated operations of this type.

Recommended Corrective Action

1. Add a requirement to the checklist to establish communications with the missile pressurization crew before commencing the fuel drain
2. Support the technical data requirements with appropriate organizational control action

Action Taken

Incident Report Number and Date	Disposition
D/D 855R August 1961	9 August 1961: PSRB approved and assigned to TDRB and 576C Site Commander (SAC) for action 16 August 1961: TDRB approved for GD/A TMCR 30 August 1961: 576C Site Commander corrected the problem by briefing personnel and by adding communications requirements to SOP 15 September 1961: TDRB cancelled TMCR action

SAFETY PROBLEM NO. 23
(HUMAN FACTORS PROBLEM NO. 140)

CONTROL OF FUEL STORAGE TANK PRESSURE

Incident

The MET/M connected the fuel drain hoses and fuel began draining back into the storage tank. A short time later, however, the fuel stopped draining due to increased storage tank pressure. The checklist and job manuals offered no help in getting the fuel to start flowing again. A GD/A engineer directed the periodic opening of the B1 bleed valve on the No. 2 fuel skid to relieve the back pressure and obtain continuous draining. Perhaps intensified by this back pressure, the drain hoses allowed a large amount of fuel to be squirted or sprayed inside the thrust section.

Job Operation/Task

Ready State B; Vertical drain residual fuel, T.O. 21-SM65E-CL-15-2, Section 22

Problem Criticality

Major

Problem Type

Safety and Technical Data or Equipment Design

System Implications

Insufficient information has been made available to R/NAA concerning the nature of this problem; system implications are therefore undetermined.

Recommended Corrective Action

Either add the steps to the procedure or correct the equipment so the extra steps are not necessary.

Action Taken

Incident Report Number and Date	Disposition
D/D 2033R 20 September 1961	11 October 1961: PSRB approved, sent to AF Safety for investigation and corrective action recommendations. NOTE: Corrective action information feedback has not indicated the specific problem nor the specific action taken. The problem has been eliminated without technical data changes; therefore, it was apparently an equipment problem.

SAFETY PROBLEM NO. 24
(HUMAN FACTORS PROBLEM NO. 166)

NEGLECTING TO USE COMMUNICATIONS SYSTEM

Incidents

On two occasions the MET/M was observed entering the missile thrust section to work, but his headset and microphone were left outside. Because of the ambient noise level, persons outside found it necessary to climb up and at least put their head into the thrust section before they could communicate with him intelligibly.

Job Operation/Task

Ready State B, Vertical Drain Residual Fuel, T.O. 21-SM65E-CL-15-2, Section 22, 11 November 1961; Wet Countdown, Return to Ready State A, Horizontal Fuel Drain, T.O. 21-SM65E-CL-17-2, Section 3, 10 November 1961.

Problem Criticality	Problem Type
Major	Safety; Organizational Controls

System Implications

The unfortunate consequences of failure to maintain two-way communications during operations of this type are voluminous. The inconvenience of climbing up to the boattail to communicate is certain to reduce the amount of communication, and eventually, a judgemental error in assessing the need to communicate will cause important information not to be disseminated. In emergency situations (e.g., that described in Human Factors Problem No. 155) the consequences could be quite disastrous. Also, the man inside the thrust section may have the need to communicate to those outside.

Recommended Corrective Action

Revise the SOP of using activities, as necessary, to ensure that the communications system will be used when appropriate.

Action Taken

Incident Report Number and Date	Disposition
D/D 2026R, 18 September 1961	6 October 1961: PSRB approved 2026 and sent to OSTF-1 Site Commander for action. 18 October 1961: 2026 returned to R/NAA with suggestion that notes be added to operational checklists requiring establishment of crew communications during fuel draining.
D/D 2250R, 2 October 1961	18 October 1961: PSRB approved 2250, asked R/NAA to hand carry to OSTF-1 Site Commander 25 October 1961: 2250 returned to R/NAA; same suggestion 26 October 1961: 2026, 2250 resubmitted to PSRB; 2026 assigned to TDRB for action

Incident Report Number and Date	Disposition
	31 October 1961: 2250 cancelled by PSRB; duplicates 2026 2 November 1961: TDRB rejected 2026: corrected by SOP

SAFETY PROBLEM NO. 25
(HUMAN FACTORS PROBLEM NO. 206)

STEPPING ON ELECTRICAL CABLES

Incident

A human factors observer noticed that test personnel were stepping on electrical test cables. A closer look revealed that numerous test cables and hoses were stretched across the floor in a random fashion (i.e., not routed through racks or tunnels) so that it was virtually impossible to work in the area without stepping on the cables.

Job Operation/Task

Missile systems checkout, T.O. 21-SM65E-CL-14-2

Problem Criticality	Problem Type
Major	Safety; Job Environment, MAB Design; Training

System Implications

Frequent stepping on electrical cables produces progressive insulation breakdown, and it is only a matter of time before electrical shock hazards develop. (Meanwhile, a mild tripping hazard exists.) With insulation breakdown, there is also the possibility of "spectre malfunction indications" during systems checkout.

Recommended Corrective Action

For existing missile assembly buildings, the test cables should be clustered into one or more cable runs and temporary wooden ramps positioned over them. For future MAB designs, covered cable trenches should be employed, where practical.

Action Taken

Incident Report Number and Date	Disposition
D/D 5425R, 1 December 1961	28 December 1961: PSRB assigned to MAB-2 Site Commander for action. 7 March 1962: Authors visited MAB-2 and noted that wooden ramps had been built and were being used.

SAFETY PROBLEM NO. 26
(HUMAN FACTORS PROBLEM NO. 237)

BUMPING HEADS ON CRANE CONTROL BOX

Incident

The human factors observer noted that the three control boxes for the two-section overhead crane were hanging approximately 4 to 5 feet above the floor, where personnel could easily bump into them.

Job Operations/Tasks

All inspection and checkout operations in the Missile Assembly and Maintenance Shops missile bays

Problem Criticality	Problem Type
Moderate	Safety; Job Environment

System Implications

No static human engineering evaluations of MAMS facility items had been conducted by R/NAA observers. This hazard was noted during actual maintenance operations.

Recommended Corrective Action

Suspend control boxes by springs or bungees about 7 feet from the floor so that they can be pulled down (to 4-1/2 feet) for use.

Action Taken

Incident Report Number and Date	Disposition
D/D 5924R, 14 March 1962	21 March 1962: PSRB held D/D for consideration 4 April 1962: PSRB approved D/D and assigned to Capt. Spowart, MAB-2, with copy to 6595th Safety

SAFETY PROBLEM NO. 27
(HUMAN FACTORS PROBLEM NO. 235)

LAUNCHER WORK PLATFORM DEFICIENCIES

Incident

The MET/M and from one to five helpers were observed having great difficulty with their footing while trying to remove blowoff covers and install thrust chamber closures and covers, booster engine gimbal locks, and the sustainer engine transport strut. The latter two tasks were not only difficult, but dangerous. The men had to lift the thrust chambers while standing precariously on tubular members of the launcher framework, or on launcher pedestals. (It was later reported and verified that one member of the usual crew was absent that day, still convalescing from a back injury received while performing these tasks several days earlier.)

Job Operations/Tasks

Missile Removal, T.O. 21-SM65E-CL-21-2, Sections 1 and 2; also Missile Installation, T.O. 21-SM65E-CL-12-2, Section 1

Problem Criticality	Problem Type
Major	Safety; Job Environment; Technical Data; Provisioning

System Implications

In January 1962, this problem was extracted from Problem 129, first reported in September 1961, because it was seen that the majority of the major hazards reported in problem 129 could be avoided by a procedural crutch (see recommended corrective action). In January, the prospects of obtaining provisioning action to correct these problems by the addition of maintenance platforms seemed small. For this reason the partial fix discussed here was recommended, even though it meant that sometimes the tasks of exchanging blowoff covers for shipping covers and closures must take place outdoors in inclement weather. These disadvantages should be compared with those discussed in relation to problem 129, which will exist until either one or the other of the two fixes is adopted. (Please note that R/NAA never intended that both fixes should be adopted, which now appears to be happening.)

Recommended Corrective Action

Relocate the problem tasks to a later section of the checklist after the missile has been moved out of the missile bay. At this time, access platforms can be stationed wherever they are needed, and a hydraulic jack can be used to lift the thrust chambers.

Action Taken

Incident Report Number and Date	Disposition
D/D 5774R, 25 January 1962	7 February 1962: PSRB assigned 5774 to TDRB and Safety 16 May 1962: TDRB approved for TMCR V-1272-II

Incident Report Number and Date	Disposition
	23 May 1962: EID 27-0375, Figure A Item 5141, rocket engine maintenance set, provides portable work platforms with integral hydraulic jack for this purpose. Platforms can be installed on launcher quadrant I and II pedestals when made available to using activities.
D/D 6015R 13 June 1962	19 June 1962: GD/A test conductor holding 6015 for review

SAFETY PROBLEM NO. 28
(HUMAN FACTORS PROBLEM NO. 129)

SLIPPERY LAUNCHER ACCESS ROUTES

Incidents

The MET/M was observed performing many operations without the benefit of safe access routes, steps, or platforms. He had to climb over, under, or around, or stand on the launcher hardware, exposing himself to injury from bumping or falling. Under certain conditions, the situation is especially hazardous because the surfaces are wet with fuel and very slippery. Sometimes, heavy lifting tasks must be performed while struggling to maintain footing atop slippery launcher hardware. At least one back injury resulted from this situation.

Job Operations/Tasks

Ready State B, Vertical Drain Residual Fuel; DPL, Horizontal Fuel Drain; Missile Installation, remove gimbal actuator locks and sustainer transport strut; Missile Removal, install gimbal actuator locks and sustainer transport strut.*

Problem Criticality	Problem Type
Major	Safety; Equipment Design Deficiency; Job Environment; Provisioning

*The operations and tasks listed are those considered the most hazardous. Every propulsion system task performed at the launch site is affected by this problem to some degree. (Also see related Human Factors Problem 235.)

System Implications

Working continually under the hazards summarized in this problem has a general degrading effect upon the maintenance morale. Personnel become rather apathetic toward many safety conditions, contamination problems, and conditions or operations which could compromise system integrity. Such conditions encourage the development of daredevil attitudes found in some accident-prone workmen, and may encourage the more responsible and mature personnel to transfer.

Recommended Corrective Action

Provide a special work platform, a special hook-type ladder, and liberal applications of nonskid paint to launcher hardware to reduce most of these hazards to a tolerable level.

Action Taken

Incident Report Number and Date	Disposition
D/D 2020R, 18 September 1961	6 October 1961: PSRB approved 2020R for R/NAA Par 24 11 October 1961: GD/A Par 38 generated on some problem 11 October 1961: PSRB approved 2249R and 2374R for Par 24 18 October 1961: PSRB approved Par 24, assigned to EDRB

Incident Report Number and Date	Disposition
	10 November 1961: PSRB approved Par 38, assigned to EDRB 16 November 1961: EDRB approved Par 38 for CRL 15 to design and provision access platform 22 November 1961: EDRB approved Par 24 23 May 1962: EID 27-9375, GD/A Figure A Item 5141, rocket engine maintenance platform set added.

SAFETY PROBLEM NO. 29
(HUMAN FACTORS PROBLEM NO. 243)

HARD HATS

Incident

In spite of rules which forbade it, an engineer deliberately wore his hard hat inside the missile thrust section to protect his head. A technician immediately reported him, and a heated argument followed concerning whether or not missile hardware does get damaged from hard hats, and whether people can teach themselves to avoid painfully bumping bare heads if they try.

Job Operation/Task

The task in progress was to lubricate the booster and sustainer gimbal bearings. However, this could have happened with any task inside the missile thrust section.

Problem Criticality	Problem Type
Moderate	Safety; Organizational Controls

System Implications

Hardware damage had been blamed on the practice of wearing hard hats inside the missile. The integrating contractor therefore issued an order forbidding this practice. This incident was not the first violation of the order, but technicians do not normally report other technicians.

Recommended Corrective Action

Investigate hardware damage attributed to hard hats. If allegations are untrue, rescind the order.

Action Taken

Incident Report Number and Date	Disposition
D/D 5841R, 12 February 1962	21 February 1962: PSRB assigned to AF Safety 8 November 1962: Safety returned D/D to R/NAA; no action indicated

SAFETY PROBLEM NO. 30
(HUMAN FACTORS PROBLEM NO. 255)

LEANING OVER BACKWARDS

Incident

The MET/M experienced considerable difficulty in trying to open the B-1 turbine spinner access door because no suitable work platform or access ladder had been provided at the launcher. He was able to reach the screws (with some difficulty) by standing on the trailer alignment rail and leaning backward and to one side. The possibility of falling was serious.

Job Operation/Task

Systems Validation, T.O. 21-SM65E-CL-13-2, Section 7, Engine Start System Checkout.

Problem Criticality	Problem Type
Major	Safety; Provisioning

System Implications

Adding this problem description to those of problems 98, 103, 129, 235, and 272 gives a total view of the work platform problem at the "E" series launcher.

Recommended Corrective Action

Provide a suitable work platform or access ladder for this purpose.

Action Taken

Incident Report Number and Date	Disposition
D/D 5868R, 14 February 1962	28 February 1962: Approved by PSRB and assigned to OSTF-1 Site Commander for action; copy to 6595th Safety.

SAFETY PROBLEM NO. 31
(HUMAN FACTORS PROBLEM NO. 262)

IMPROVISED WORKSTANDS AND TRIPPING HAZARDS

Incident

The MET/M was carrying some tools and test equipment up the ramp onto the missile maintenance platforms (in MAB-2, missile bay 2). In stepping over a folded guard rail he did not lift his feet quite high enough and almost tripped and fell. He stumbled in the direction of the side of the platform which had no guard rail. For the duration of the observation, every person who came up or down the ramp, to or from the missile maintenance platform, stumbled over this folded guard rail.

Equipment Affected

Work platform set 27-97020-1

Job Operation/Task

Systems Checkout, T.O. 21-SM65E-CL-7-3; Task 121.1A/75002, Prepare propulsion system for checkout

Problem Criticality	Problem Type
Major	Safety; Provisioning

System Implications

This incident occurred because only one complete set of work platforms had been provided for the MAB. Thus, whenever similar tasks are being performed in both missile bays, one crew must improvise by using a workstand designed for another purpose. Guard rails which obstruct access routes must be folded down, creating the subject tripping hazards. Also, there are usually one or more edges which need guard rails and do not have them, thus amplifying the hazards.

Recommended Corrective Action

Either provide two complete sets of work platforms for each MAB, or avoid scheduling simultaneous accomplishment of scheduled or unscheduled maintenance in the same areas in both missile bays.

Action Taken

Incident Report Number and Date	Disposition
D/D 5937R, 27 March 1962	4 April 1962: PSRB approved and submitted to SAC for investigation and action (Capt. Smith) 2 May 1962: SAC replied that UR action has been initiated (UR number was not mentioned) May 1962: SOP revised; use of maintenance platforms for other than intended use so that guard rails are missing where needed, or folded, is forbidden June 1962: Human factors observer noticed that two complete sets of platforms were in use in MAB-2.

SAFETY PROBLEM NO. 32
(HUMAN FACTORS PROBLEM NO. 276)

MAINTAIN GROUND EQUIPMENT, TOO

Incident

A missile arrived from the MAB and was being installed on the OSTF-1 launcher. When the MET/M removed the B-1 exit closure, it was found to have been installed with one protective pad missing from the closure retaining rod. The thrust chamber fuel tubes in the combustion zone had been scraped by the retaining rod foot, but a careful inspection determined that the damage was not critical.

Equipment Affected

LR89NA-5 booster engine; RX20041 booster thrust chamber exit closure; RX20299-3 pad.

Job Operation/Task

Checklist AP62-0132, section 37, Missile Installation (4 June 1962)

Problem Criticality	Problem Type
Major	Equipment Safety; Organizational Control

System Implications

Although the damage to the B-1 engine on this missile (67E) was superficial, it is believed that this practice, if permitted to continue, will result in critical damage to an engine.

Recommended Corrective Action

Use better judgement in the use and maintenance of equipment which can vitally affect engine performance.

Action Taken

Incident Report Number and Date	Disposition
D/D 6039R, 18 June 1962	25 July 1962: PSRB assigned to MAB-2 Site Commander

SAFETY PROBLEM NO. 33
(HUMAN FACTORS PROBLEM NO. 274)

SHIPPING COVERS VS TEST PLATES

Incident

A MET/M got the gas generator test plate (P/N 9011329) from the G3087 sustainer engine plate and plug kit and began to remove the thin, plastic shipping cover to install the test plate in preparation for leak tests. The test engineer stopped him. The tests were run using the shipping cover in lieu of the test plate. The test engineer justified this deviation from the approved procedure by explaining that the test plate "...took too long to install and remove."

Job Operation/Task

Checklist AP62-0133, Section 35, Sustainer Engine Checkout (21 May 1962)

Problem Criticality

Major

Problem Type

Safety; Job Environment; Organizational Controls

System Implications

During these leak test operations, a pneumatic pressure of 7 $\pm$1 psi is applied to the gas generator system in sufficient volume that, should the shipping cover fail during this usage for which it was not intended, flying pieces of plastic could cause personnel injury.

No tests were run to determine how much time is saved by this unorthodox procedure, but an experienced MET/M estimated that it might be as much as 5 minutes.

Several crew members were interviewed by the human factors observer in an effort to determine why such risks would be taken for such a small time saving. It was unanimously reported that the civilian test engineer was solely responsible, and his error apparently stemmed from somewhat misdirected motives.

Recommended Corrective Action

Discontinue using shipping covers in lieu of test plates or test plugs. In the future, perhaps shipping covers can be designed sufficiently rugged to permit this dual function.

Action Taken

Incident Report Number and Date	Disposition
D/D 6032R 15 June 1962	25 July 1962: PSRB assigned to Capt. Spowart, BSD, MAB-2; information copies to 6595th Safety

SAFETY PROBLEM NO. 34
(HUMAN FACTORS PROBLEM NO. 252)

ADJUSTABLE WRENCHES

Incident

The human factors observer noted that the technician was using a crescent wrench to remove the plugs in the B-1 gas generator igniter bosses.

Equipment Affected

LR89NA-5 booster engine

Job Operation/Task

Ready State "A" Training, T.O. 21-SM65E-CL-18-2, Section 1, Missile Explosive Assemblies Checkout and Installation

Problem Criticality	Problem Type
Major	Safety; Training

System Implications

Adjustable wrenches are never to be used on rocket engine hardware. If the wrench jaws are not parallel, or if the wrench is not carefully adjusted on the fitting, the hex is easily stripped. A stripped hex on this plug could be quite serious since the drilling and tapping operations could damage the igniter boss threads and introduce metal clips into the gas generator. This could result in damage to the turbine. The technician indicated that he did not know that this practice is taboo.

Recommended Corrective Action

Instruct all propulsion system maintenance personnel in the proper selection and use of wrenches.

Action Taken

Incident Report Number and Date	Disposition
D/D 5884R 19 February 1962	28 February 1962: PSRB assigned to OSTF-1 Site Commander for action

SAFETY PROBLEM NO. 35
(HUMAN FACTORS PROBLEM NO. 248)

BLOCKED SAFETY AISLES

Incident

On several occasions, the human factors observer noticed that the MAB safety aisles were obstructed by (1) careless positioning of workstands or safety barricades, or (2) improper location of test equipment, blueprint tables, etc.

Job Operations/Tasks

All of those associated with the MAMS Receiving Inspection, T.O. 21-SM65E-CL-3-3, and Systems Checkout, T.O. 21-SM65E-CL-7-3.

Problem Criticality	Problem Type
Moderate to major, depending on extent obstructed	Safety; Job Environment

System Implications

Both the north and south aisles were obstructed. In an emergency, medical personnel could not utilize the aisles carrying a stretcher, and excessive time would be required to evacuate personnel from the area.

Recommended Corrective Action

Observe the painted lines demarking the safety aisles and keep both aisles clear.

Action Taken

Incident Report Number and Date	Disposition
D/D 5968R, 13 Februa ry 1962	February 1962: Not processed through PSRB because AF personnel were not directly responsible for these errors. 8 May 1962: Rejected by R/NAA PSS analysis because the problem no longer exists

SAFETY PROBLEM NO. 36
(HUMAN FACTORS PROBLEM NO. 216)

USING TURBOPUMPS FOR STEPLADDERS

Incidents

On eight separate occasions the human factors observers reported from one to six technicians using the booster turbopump volutes and high-pressure propellant ducting as steps in climbing to the top of the missile. In six instances, the access ladder which should have been used was removed temporarily to permit the accomplishment of tasks with which it physically interfered. However, in the other two cases the ladder was in place and could easily have been used. In no case was there such urgency that the practice could be considered justified for the sake of expediency.

Equipment Affected

LR89NA-5 booster engines on missiles 64E, 66E, 67E, and 65E

Job Operations/Tasks

T.O. 21-SM65E-CL-7-3, Systems Checkout, Section 21, Vernier Engine Solo System Leak Check; Checklist AP62-0133, Section 34, Vernier Engine Solo System Checkout; AP62-0133, Section 24, Hydraulic Fill and Bleed; and undesignated unscheduled maintenance.

Problem Criticality | **Problem Type**

Major | Safety; Organizational Controls; Training

System Implications

In all but one case the (interfering) tasks were completed and the ladder already should have been returned to its proper position. Nevertheless, it would have taken about 1 minute for four men to reposition it.* (For the one exception the delay might have been as much as 30 minutes.) Stepping on the volutes and ducts scratches the ducts and places undue stress on flanges and seals. It also damages electrical wiring to heaters and instrumentation. Missiles on which this practice has been tolerated could be studied to determine possible effects on propulsion system performance at launch (although a direct cause-and-effect relationship would be hard to prove).

Recommended Corrective Action

1. For any task which requires temporary removal of the No. 1 vernier engine access ladder and maintenance platform, make the reinstallation one of the final steps of the task.
2. Employ organizational controls (as strong as necessary) to guarantee that no one climbs on the engines for any reason.

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*See Problem 221 for a suggested means of improving this situation.

Action Taken

Incident Report Number and Date	Disposition
D/D 5446R, 12 December 1961	28 December 1961: PSRB assigned action to the MAB-2 Site Commander
	3 January 1962: PSRB assigned supplementary action to TDRB
	12 January 1962: MAB-2 Site Commander reports that (unspecified) corrective action has been taken
D/D 5969R, 8 March 1962	8 May 1962: PSRB rejected D/D 5969R because "duplicate of D/D 5446R."
D/D 6022R, 13 June 1962	25 July 1962: PSRB assigned to Capt. Spowart, BSD MAB-2 Site Commander
D/D 6035R, 15 June 1962	26 June 1962: D/D 6035R cancelled by R/NAA PSS analyst because "...duplicate of D/D 6022R."
D/D 6272R, 2 October 1962	22 October 1962: PSRB assigned to Capt. Spowart
D/D 6294R, 5 October 1962	19 October 1962: D/D 6294R cancelled by R/NAA PSS analyst because "...duplicate of D/D 6296R."
D/D 6296R, 9 October 1962	5 November 1962: PSRB assigned to Capt. Spowart
D/D 6305R, 25 October 1962	19 November 1962: PSRB assigned to Capt. Spowart

SAFETY PROBLEM NO. 37
(HUMAN FACTORS PROBLEM NO. 291)

MAINTENANCE OF PLATES AND PLUGS KITS

Incidents

On three occasions within as many days the MET/M could not use the test plate and adapter which were required because they had not been maintained properly. A closer examination of the plates and plugs kits disclosed that these particular plates and adapters were not the only ones which could not be used. Most of the adapter assemblies had been disassembled; several of the original parts had been cannibalized for other equipment. Some effort had been made to reassemble some adapters, but none of these was correctly reassembled. Many were so badly contaminated that the MAMS cleaning facilities could not restore them to a LOX-clean condition. It had become customary to improvise test connections, which often did not contain the relief valve features of the approved test hardware.

Equipment Affected

G3080 Booster Engine Plates and Plugs kit KMU-15/E; G3087 Sustainer Engine Plates and Plugs kit KMU-16/E

Job Operations/Tasks

Checklist AP62-0133, Section 34, Vernier Engine Solo System Checkout (11 July 1962); Section 36, Booster Engine System Checkout (11 July 1962)

Problem Criticality	Problem Type
Major	Safety; Job Environment; Organizational Controls

System Implications

Improvising test connections is a dangerous practice from many different viewpoints, but it becomes particularly hazardous when combined with such problems as human factors problem No. 290 (HPU Line 3 vs Line 4) and 274 (Test Plates vs Shipping Covers). Not only does it compromise the protective measures intended to prevent equipment damage, but it frequently has a snowballing effect in that it also forces improvisations of procedures, task scheduling, manning, etc., which create further problems. If the test equipment is not properly maintained, there is only one way to keep personnel from improvising test connections, and that is to relax maintenance schedules, i.e., do not have them do the operations in question until the equipment is usable. Since this is obviously an unsatisfactory procedure, it should serve to emphasize the importance of proper maintenance of all AGE.

Present practices concerning responsibility for and frequency of maintenance on these plates and plugs kits have not yet been thoroughly studied. Apparently, the personnel who use this equipment (AFSC 443X1A MET/Ms) are charged, jointly, with the responsibility for its maintenance between scheduled (periodic) inspections. However, this mutual responsibility is somewhat loose and vague as to its execution. It appears that positive corrective action can be evaded at least until the next periodic inspection (which occurs at 6-calendar-month intervals). If this comprehensive inspection is adequately supported by local SOP and other organizational controls, the noted discrepancies would probably be detected and corrected at that time.

Recommended Corrective Action

Place the plates and plugs kits under tool crib jurisdiction. Require that a knowledgeable tool crib attendant check the kits for completeness, contamination, and proper maintenance before allowing the MET/M's to turn them in or check them out. Use whatever organizational controls are appropriate and necessary to stop cannibalization of test kits and guarantee conscientious performance of maintenance duties.

Action Taken

Incident Report Number and Date	Disposition
D/D 6206R 7 August 1962 D/D 6210R, 9 August 1962 D/D 6212R, 9 August 1962	10 September 1962: PSRB assigned all three reports to Capt. Spowart, BSD, MAB-2

SAFETY PROBLEM NO. 38
(HUMAN FACTORS PROBLEM NO. 288)

TEAMWORK REQUIRES TEAM PRACTICE

Incident

The human factors observer noticed that the test crew was not proceeding strictly by the checklist. In a short time, the MET/M was ahead of the others. He was busily performing a leak check of the vernier engine solo system with no pressure applied as yet. This error was detected and corrected, but the occasioning error of not following checklist sequence was continued. Again, the MET/M got ahead of the others. He began to open the pressure regulator on the 50 to 600 supply panel before the supply shutoff valve had been opened to admit pressure to the panel. Because of the hazards involved, the observer broke silence and called the situation to his attention. As he began to close the regulator, one of the other crew members opened the supply shutoff valve. The pressure surge apparently damaged the supply gage so that it had to be removed and repaired.

Equipment Affected

G3077 Electrical Pneumatic Systems Test Stand AF/E47T-1

Job Operation/Task

Checklist AP62-0133, section 34, vernier engine solo system checkout (11 July 1962)

Problem Criticality

Major

Problem Type

Safety; Training; Organizational Controls

System Implications

Many of the comments made on problems 230, 285, and 154 could be repeated here, but there are other implications. The MET/M who had contributed most toward these errors had received the least Operational Readiness Training. During ORT, such errors are quite common; however, the instructors are skilled in prognostication, and usually are able to intercede before actual equipment damage has occurred.

Until the technicians have made a few errors of this type, it seems that they just cannot understand why it is important to follow checklists carefully, and why teamwork is important (as opposed to going ahead on one's own tasks as fast as one can without due regard for the progress achieved by the other crew members). In other words, it takes a few failures resulting from incomplete teamwork to prove the necessity of thorough teamwork before the technician is adequately motivated and properly oriented to learn from the present practice situation the cooperative skills, attitudes, and work habits that will be needed later.

Recommended Corrective Action

This particular MET/M needed more training on the G3077. Also, he should have completed ORT before assignment to an operational site. Recommendations made on Problem 285 concerning the use of training and organizational controls to inculcate proper use of technical data also apply here.

Action Taken

Incident Report Number and Date	Disposition
D/D 6201R, 7 August 1962 D/D 6202R, 7 August 1962	10 September 1962: PSRB assigned both D/D's to Capt. Spowart, BSD MAB-2 Site Commander

SAFETY PROBLEM NO. 39
(HUMAN FACTORS PROBLEM NO. 236)

REMOVE LOCKS AND COVERS BEFORE LAUNCH

Incidents

On two separate occasions a human factors observer noticed that a fuel duct cover, gimbal actuator locks, and a transport strut were painted yellow or grey. It was his understanding that such equipment should be red and have attention-getting red streamers attached to reduce human errors in quickly determining whether the equipment is removed or installed.

Problem Criticality	Problem Type
Major	Safety; Equipment Design

System Implications

Air Force System Control document 80-6 (C.4-3.6) requires that all equipment such as locks, covers, and supports which must be removed before flight shall be painted red and (if not sufficiently conspicuous already) have a red streamer attached. On two missiles (64E and 66E) the noted items were not red and had no streamers. Failure to remove any one of them before launch could result in mission failure. Failure to install them before transport or certain maintenance operations could result in hardware damage.

Recommended Corrective Action

Comply with AFSC 80-6

Action Taken

Incident Report Number and Date	Disposition
D/D 5775R, 30 January 1962	7 February 1962: PSRB assigned to Air Force Systems Command Quality Control
D/D 5793R, 1 February 1962	March 1962: Red fuel duct cover observed in use on Missile 67E
	November 1962: Some yellow and gray locks and covers still in use.

SAFETY PROBLEM NO. 40
(HUMAN FACTORS PROBLEM NO. 284)

INTERFERENCE WITH SUSTAINER HYPERGOL CARTRIDGE

Incident

A MET/M had difficulty installing the sustainer hypergol cartridge. Before the cartridge was properly aligned with the hypergol container so it could be inserted, the aft end of the cartridge struck a welded bracket on the thrust chamber which is used for attaching the shipping strut. The MET/M finally found a position in which he could exert sufficient pull on the container to spring it outboard about 3/16 inch, which allowed the cartridge to clear the bracket and enter the container. A slip of the hand at the wrong moment could have resulted in a ruptured cartridge and a devastating fire (triethylaluminum and triethylboron).

Job Operation/Task

Checklist AP62-0132, Section 68, Ready State A Training (4 June 1962)

Problem Criticality	Problem Type
Major	Safety; Job Environment; Manufacturing Error

System Implications

Because the sustainer hypergol container is mounted by clamping it to a turbopump strut, it can assume a variety of positions during assembly operations. If the mouth of the container is tilted inboard too much, the problem described above occurs. This problem is not new. It was first discovered at a Santa Susana test stand on one of the earliest MA-3 sustainer engines. As a result, Rocketdyne Quality Control added one item to their inspection buyoff on the hypergol container installation: a test fixture (dummy hypergol cartridge) was to be inserted in the container mouth and the clearance between cartridge and bracket was to be at least 0.05 inch. However, no production change point was established, and no change was made to the engineering drawing. Therefore, most of the related maintenance and modification instructions produced by R/NAA and the integrating contractor were lacking in this dimensional requirement.

Although the incident recorded here was probably the result of maintenance or modification after the engine left the Rocketdyne plant, it did occur before the missile was turned over to the Air Force and must therefore be classified a manufacturing error.

Recommended Corrective Action

For this particular engine, the hypergol container should be repositioned to provide adequate clearance. To prevent recurrences of this problem on future engines, the clearance dimensions should be specified on the engineering drawing so that they will be automatically picked up and included in maintenance and modification instructions.

Action Taken

Incident Report Number and Date	Disposition
D/D 6125R, 5 July 1962	25 July 1962: PSRB assigned to R/NAA Canoga 12 July 1962: Clearance dimension corrected on Missile 67E 20 July 1962: R change to drawing 400120, note 10 and view R; add the clearance requirement for engines, serial No. 2892, and subsequent.

SAFETY PROBLEM NO. 41
(HUMAN FACTORS PROBLEM NO. 290)

NCU LINE 3 VS LINE 4

Incident

The checklist called for connecting NCU line 3 (pressure range 40 to 250 psig) to the vernier engine; line 4 (pressure range 0 to 1000 psig) was used instead.

Job Operation/Task

Checklist AP62-0133, Section 34, Vernier Engine Solo System Checkout (11 July 1962).

Problem Criticality	Problem Type
Major	Safety; Organization Controls

System Implication

There are two NCU's in MAB-2. Line 3 on the first NCU had been contaminated earlier. The action to determine how it happened and to prevent its recurrence was apparently ineffective because the same line on the other

NCU was later contaminated. Since neither line 3 could be used, this caused the test crew to try the hazardous substitution described above, creating a basic situation conducive to overpressurizing engine systems. Coupled with human factors problem 291, this problem becomes extremely dangerous.

Recommended Corrective Action

Determine what causes line 3 to become contaminated and fix it. Decontaminate line 3. Discontinue engine testing until line 3 is useable or be positive that the engine systems are protected with relief valves capable of handling the pressure and volume of NCU line 4.

Action Taken

Incident Report Number and Date	Disposition
D/D 6205R 7 August 1962	10 September 1962: PSRB assigned to Capt. Spowart, MAB-2.

SAFETY PROBLEM NO. 42
(HUMAN FACTORS PROBLEM NO. 168)

HIGH-PRESSURE HOSE TIEDOWN

Incident

The MET/M was observed using a test hose containing 1000 psig pneumatic pressure, but with no sand bags or tiedown cables.

Job Operation/Task

Ready State B, Propulsion System Setup for DPL; Pressurize the Sustainer Engine Hydraulic Accumulator, T.O. 21-SM65E-CL-15-2, Section 8, 11 November 1961.

Problem Criticality

Major

Problem Type

Safety; Training; Organizational Control; Job Environment

System Implications

Test hoses sometimes do rupture, and if not properly anchored with sandbags (or shot bags) and tiedown cables, the pressurized fragment will whip violently until pressure is depleted or shut off. Personnel and equipment can be seriously harmed. The few minutes saved by skipping this standard safety precaution are not worth the risks involved.

Recommended Corrective Action

Since the requirement to tie down high-pressure hoses is already included in the related technical data, corrective action should consist of the use of organizational controls to enforce the requirement and the addition of supporting information and practice during Operational Readiness Training.

Action Taken

Incident Report Number and Date	Disposition
D/D 2253R, 3 October 1961	11 October 1961: PSRB assigned to Site Commander and EDRB. 16 November 1961: EDRB rejected, sent to TDRB 22 November 1961: TDRB rejected, "Training problem" 29 November 1961: PSRB returned to TDRB 16 January 1962: TDRB rejected, "Training problem" 14 February 1962: PSRB reassigned to EDRB which is holding D/D in abeyance.

SAFETY PROBLEM NO. 43
(HUMAN FACTORS PROBLEM NO. 272)

THE FLAME-BUCKET NET IS FOR PEOPLE

Incidents

On two occasions, a human factors observer saw the MET/M's remove engine blowoff covers, thrust chamber covers, and the sustainer engine support strut, and toss them into the flame-bucket net.

Job Operations/Tasks

Checklist AP 62-0132, Section 30, Missile Removal (4 June 1962), and Section 37, Missile Installation (4 June 1962).

Problem Criticality	Problem Type
Major	Safety; Job Environment; Organizational Controls

System Implications

This problem illustrates the old axiom that when bad conditions are condoned, they multiply. Problems 98 and 103 (July 1961) were concerned with the absence of safe footing for maintenance personnel at the launcher. Problems 129, 235 and 255 disclosed further areas where this same condition was prevalent. Now, because the MET/M's do not have secure footing, they cannot handle large or heavy pieces of equipment after removal and are obliged to toss them into the flame-bucket net, which was intended to protect people from injury resulting from falls into the flame bucket. Should anyone fall while this equipment is in the net they would probably be seriously injured.

Recommended Corrective Action

Assign an extra helper to the MET/M's during these tasks. Covers, closures, and struts can be handed to the helper instead of tossing them into the net. (This would not require a manning change because extra people are available at the stipulated times.)

Action Taken

Incident Report Number and Date	Disposition
D/D 6013R, 13 June 1962	20 June 1962: PSRB assigned 6013R to OSTF-1 Site Commander for corrective action 25 July 1962: PSRB assigned 6038R to OSTF-1 Site Commander NOTE: The portable rocket engine maintenance platform set provided to resolve problem 235 is expected to help with this problem also.

SAFETY PROBLEM NO. 44
(HUMAN FACTORS PROBLEM NO. 211)

THRUST CHAMBER PAD NOT USED

Incidents

On four separate occasions, human factors observers noticed that technicians were not using the pad to protect the thrust chamber fuel tubes from dents, scratches, and punctures when they were working inside the thrust chamber. On two occasions, a thin sheet of vinyl plastic was used instead. On one occasion, a bunk mattress was used, and on another occasion, nothing was used.

Equipment Affected

LR89-NA5 booster engine; 9011565 thrust chamber pad.

Job Operations/Tasks

Systems Checkout, T.O. 21-SM65E-CL-7-3 and T.O. 21-SM65E-2J-3-1; particularly such tasks as installing or removing thrust chamber throat plug, cleaning, inspecting, etc.

Problem Criticality	Problem Type
Major	Safety; Organizational Controls

System Implications

This practice can cause a mission failure by degrading engine operation. A sharp-radius scratch will often split. Small splits and punctures cause fuel leaks which reduce tube cooling downstream from the leak. Overheated tubes erode and make bigger leaks. These, in turn, produce thrust losses and sometimes explosions. The substitution of the bunk mattress was satisfactory for protecting the engine if it could be kept in place. (Since it was approximately 2 feet too long, it tended to slide out of position.) The vinyl sheet afforded some protection from scratching, but virtually none from dents or punctures. In all four cases, the person responsible for not using the pad mentioned some difficulty in finding it; however, in three cases, there was reason to doubt that a very exhaustive search had been conducted.

Recommended Corrective Action

Have a regular place to store the 9011565 pad when it is not in use. Make certain that all personnel know where to store it. Encourage them to use it and to return it to its proper place when through.

Action Taken

Incident Report Number and Date	Disposition
D/D 5441R, 6 December 1961	28 December 1961: PSRB assigned to MAB Site Commander 12 January 1962: (unspecified) Corrective action complete
D/D 5450R, 14 December 1961	Cancelled. (Duplicates D/D 5441R)
D/D 6023R, 16 June 1962	25 July 1962: PSRB assigned to Capt. Spowart, MAB-2
D/D 6314R, 26 October 1962	26 November 1962: PSRB assigned to Capt. Spowart, MAB-2

SAFETY PROBLEM NO. 45
(HUMAN FACTORS PROBLEM NO. 213)

MISALIGNED MAINTENANCE PLATFORMS

Incident

The MET/M hastily pushed the maintenance platforms up to the missile boattail section in preparation for the MAMS fourth periodic checkout operations, and he did not take time to align them properly. A large gap (approximately 1 by 3 feet) remained where personnel would normally expect to step onto a platform when leaving the missile thrust section. A nasty fall could have resulted.

Equipment Affected

Task 75002/121.1A, Install Maintenance Platforms, T.O. 21-SM65E-CL-3-3.

Problem Criticality	Problem Type
Major	Safety; Job Environment; Organizational Controls; Training

System Implications

The only quality control checks and balances built into many personnel subsystems is the basic, underlying assumption that people will do correctly a task which directly affects their own personal safety. This incident is one of several (e.g., 154, 168, 223) which demonstrates that this assumption is not always correct.

Recommended Corrective Action

A stand talker, or task controller, or leadman function seems necessary during this type of operation. This person should be trained, motivated, and oriented to feel responsible for the safety of his crew. In addition to this, each maintenance crew should have a safety committeeman who would identify more completely with personnel and equipment, safety goals.

Action Taken

Incident Report Number and Date	Disposition
D/D 5443R, 29 November 1961	28 December 1961: PSRB assigned action to GD/A for Par action

SAFETY PROBLEM NO. 46
(HUMAN FACTORS PROBLEM NO. 199)

POWER OFF BEFORE REMOVING EXPLOSIVES

Incident

The MET/M was slow in performing the steps for which he was responsible during the task of removing the missile battery and explosives. He studied his checklist procedures for a long time and was not certain that he was doing the right things, particularly in regard to turning the power off. The checklist did not say which power, how many places, or where. He finally deduced what was needed and completed the job correctly, but, obviously, there was too much possibility of making a serious error.

Job Operation/Task

Missile Removal, Re-Entry Vehicle and Missile Explosive Assemblies Removal, T.O. 21-SM65E-CL-21-2, Section 1, 24 November 1961.*

Problem Criticality	Problem Type
Major	Safety; Technical Data

*NOTE: The same difficulty may be expected with the explosives installation tasks contained in Section 1 of T.O. 21-SM65E-CL-18-2 (18 November 1961) and T.O. 21-SM65E-CL-19-2 (11 December 1961).

System Implications

If power is not turned off first, it is fairly easy to brush the male electrical connector pins accidentally in the SPGG initiator leads with a hot contact. If the shorting plugs are not installed immediately, it is even possible to generate inductively enough counter EMF to fire the SPGG initiators or LPGG igniters when nearby engine heaters are disconnected. An actual instance of the former occurred at Forbes AFB approximately 2 weeks after this problem was first discovered and reported. In that case, the sustainer SPGG was fired, and resulted in destruction of the sustainer turbopump assembly.

Recommended Corrective Action

Revise the wording on checklist pages 1-1 and 1-2 to provide complete, clear, and correct requirements (suggested wording was attached to D/D). In the future, there should be some systems safety engineering review of the integrated technical data where engine explosives are involved.

Action Taken

Incident Report Number and Date	Disposition
D/D 5261R, 6 December 1961	13 December 1961: PSRB approved, assigned to TDRB and AF Safety 16 January 1962: TDRB approved for GD/A TMCR, subject to GD/A engineering approval.

Incident Report Number and Date	Disposition
	27 February 1962: TDRB held in abeyance 10 May 1962: TDRB approved for TMCR V1272 II 15 July 1962: Recommended changes appeared in 15 July revision to Checklist AP62-0132, Section 60.

SAFETY PROBLEM NO. 47
(HUMAN FACTORS PROBLEM NO. 155)

MIXING FUEL AND LIQUID OXYGEN FUMES

Incident

The MOCAM crew was busily draining residual fuel after a dual propellant loading exercise when someone noticed clouds of liquid oxygen fumes billowing through the open fire door between the missile bay and the liquid oxygen storage room, where another crew was loading liquid oxygen. Since the fire door could not be closed quickly, all operations were quickly shut down and all personnel were evacuated until the fumes were cleared.

Job Operation/Task

T.O. 21-SM65E-CL-17-2, Section 3, Return to Ready State A; liquid oxygen loading task name and technical data not available.

Problem Criticality	Problem Type
Major	Safety

System Implications

The firex hose is connected in the liquid oxygen storage room and is routed out to the launcher during residual fuel drain and return to ready state A procedures. Naturally, the fire door between the liquid oxygen storage room and the missile bay cannot be closed and secured while the firex hose is in use. This means that these two tasks are incompatible and cannot be scheduled for simultaneous accomplishment unless a new firex hose faucet is added in the missile bay or in areas accessible while fuel draining is in progress.

Recommended Corrective Action

Revise standard operating procedures, as necessary to guarantee that these operations are not attempted simultaneously again.

Action Taken

Incident Report Number and Date	Disposition
D/D 2166R, 28 September 1961	29 September 1961: PSS Director hand carried one copy of D/D to Site Commander 4 October 1961: PSRB assigned to GD/A for action 11 October 1961: OSTF-1 SOP reported changed to prevent recurrence of this incident 18 October 1961: PSRB sent copies of D/D to TDRB and 6595th Safety for evaluation of possible action 24 October 1961: TDRB rejected D/D: "This is a training problem." 29 November 1961: PSRB considered problem resolved, therefore closed action.

SECTION 3

SUPPLEMENTAL INFORMATION

Quantitative and qualitative safety data from various sources

The preceding section presented specific incidents from system test operations which were observed by trained human factors observer/analysts. This section supplements those field test data by presenting pertinent system safety engineering data which were obtained by surveillance or sampling of the failure reporting system, test reporting systems, and special studies. Additional data are presented which relate to the empirical nature of system test and evaluation exercises involving safety test objectives.

SUPPLEMENTAL INFORMATION

PART 1. FAILURE REPORTS

INTRODUCTION

Missile and space system programs are now required to have established procedures for the generation, transmittal, storage, and analysis of information relating to failures, malfunctions, deficiencies or troubles discovered by the contractor, subcontractor, associate contractors, military or government representatives. Procedures should also have been established for immediate corrective action and failure recurrence control. Data may be reported from manufacturing, assembly, inspection, test, and use of system hardware.

One important aspect of these failure (or operation, failure, and operating time) reporting systems is that surveillance and analysis of all human-initiated failures, human error, or faulty acts should be made by specialists skilled in human factors engineering.*

Such an established procedure for reporting hardware failure, cycle, and/or operating time data (which includes a provision for reporting human error data) would seem to provide an ideal framework for obtaining input data, maintaining surveillance, and initiating analyses relative to systems safety objectives.

*AFBM Exhibit 58-10, Reliability Program for Ballistic Missile and Space Systems, 1 June 1959, 34.

NASA Quality Publication 200-2, Quality Control Provision for Space System Contractors, 1 March 1962, 36-37.

SYSTEM SAFETY CRITICALITY EVALUATION

Various Air Force documents* now require that contractors identify system functions, malfunctions, and procedures; perform a hazard evaluation; and rate each according to a four-point system safety scale (safe, marginal, critical, and catastrophic).

To determine how a system safety criticality rating should be made, an attempt was made to rate a series of operation and failure reports (OFR's). This necessitated the formulation of more definitive criteria for the rating process (Table 2) and a set of assumptions and limitations (Table 3).

To assess the consistency between raters (i.e., would different individuals demonstrate gross differences in attempting to supply the rating criteria?), a mutually independent rating was obtained from three different raters evaluating three different sets of failure reports (Table 1). The differences obtained were in a logically predictable direction, and an assumption of inter-rater consistency can therefore be postulated.

For the purposes of this study, the evaluation was made only of operation and failure reports (OFR's) submitted during 1962. The "Advanced" rocket engine system reports were submitted as a result of receiving inspection, pretest electrical and mechanical checkout, and poststatic firing operations.

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*Proposed General Specification for Missile/Space System Safety, (par. 3.2.10 Safety Analyses), BSD Exhibit 62-41, 5 October 1962 (par 3.2.10.2 Safety Analyses) and SSD Exhibit 62-161, 1 November 1962.

The "Early" rocket engine system reports were submitted as a result of early research and development testing. The "Late" rocket engine system reports were submitted as a result of customer receiving inspection, operational exercises, and field usage.

This evaluation indicates that more than half of the failures reported were of a nature that they could have resulted in an operationally hazardous condition (if they occurred during launch operations involving a manned vehicle). However, only a small percentage were of a serious nature. (It should be cautioned that this evaluation was in terms of potential resultant consequences, did not fully consider the likelihood of detection and correction, did not consider current engineering changes or remedies nor does it present the results of effects which are reflected in normal reliability growth curves.)

The use of data from failure data reporting systems would emphasize potential safety design and procedural problems (in contrast to the post facto corrective emphasis of an accident/incident reporting system).

Additional system safety criticality rating information is contained in Section 1, Part 4, and Section 3, Part 2.

TABLE 1

SYSTEM SAFETY CRITICALITY EVALUATION OF
OPERATION AND FAILURE REPORTS
(An Evaluation of Three Different Systems by Three Different Raters)

Safety Classification	System Development Stage		
	Early (N = 163), percent	Advanced (N = 100), percent	Late (N = 101), percent
	Rater A	Rater B	Rater C
Safe	30.0	45.0	49.5
Marginal	30.0	33.0	29.7
Critical	34.5	17.0	13.9
Catastrophic	5.5	5.0	6.9

NOTE: The decrease in Critical reports would be expected as time elapsed during the system development cycle.

TABLE 2

SAFETY CRITICALITY CODE

Classification and Code	Definition*	Examples **
Safe (S)	Would not result in equipment damage or personnel injury	Instrumentation failures, connector bent pins, check valve leakage, wrong caps on drains, B-nut sleeve jammed or frozen, minor fuzz leaks of thrust chamber
Marginal (M)	Resultant problems could be detected and counteracted without major damage or injury	Damaged electrical harness, B-nuts overtorqued, gas generator igniter loose tube, ignition monitor valve not adjusted, too high gearcase vibration, gas generator liquid oxygen valve slow start, burnt insert in electrical harness, fuel poppet seat leak, aspirator or fuel tubes dented
Critical (C)	Could result in substantial damage or injury	Flange scratches, fuel ratio changes, loose bearings, turbopump nuts undertorqued, liquid oxygen dome bolts incorrectly torqued, incorrect marking on hypergol containers
Catastrophic (K)	Could result in extensive or major damage and injuries	Turbopump contamination, delayed SPGG ignition, inadvertent SPGG ignition, throat plug not removed

*Pertains to human error, design deficiency, or component malfunction

**Based upon the specific cases analyzed in this study

TABLE 3

SAFETY CODING ASSUMPTIONS AND LIMITATIONS

Assumptions in the Classification Process

1. Evaluation was made in terms of potential hazards (not what actually did happen). This was done to obtain some measure of agreement, for purposes of comparison, between: (1) the rating of potential design and procedural problems in a design review of drawing surveillance situation, (2) the rating of reports from a failure reporting system, and (3) the rating of essentially post facto accident/incident reports.

2. The evaluation was in terms of what could have happened, had it happened and gone undetected, immediately before or during launch operations involving a manned vehicle.

Limitations in Interpreting the Results

1. It is important to emphasize that the classification of any problem would be dependent upon the circumstances surrounding that case (i.e., if leakage, how much, where, when, how discovered, etc.). Therefore, the rater judgment is dependent upon:

   a. The amount of descriptive detail and significant information available to him (particularly in historical records)

   b. Any uncontrolled element of personal judgement by the rater (based upon his assessment of the current consensual technical merit of various problem areas and as influenced by the bias introduced in terms of the purposes of the evaluation)

   c. Availability of an estimation of the quantitative probability of occurrence and likelihood of various possible consequences (i.e., commonly occurring problems may be either degraded by familiarity or emphasized by chronicity and recidivism)

2. Since such an evaluation was in terms of potential resultant consequences, the final percentages obtained may not fully reflect:

b. Any uncontrolled element of personal judgement by the rater (based upon his assessment of the current consensual technical merit of various problem areas and as influenced by the bias introduced in terms of the purposes of the evaluation)

c. Availability of an estimation of the quantitative probability of occurrence and the likelihood of various possible consequences (i.e., commonly occurring problems may be either degraded by familiarity or emphasized by chronicity and recidivism)

2. Since such an evaluation was in terms of potential resultant consequences, the final percentages obtained may not fully reflect:

   a. Likelihood of detection and correction

   b. Current engineering changes or procedural remedies which are in process

   c. Cumulative or interaction effects which are reflected in normal reliability growth curves

   d. Bias in the source of the population sampled (i.e., if minor problems are quickly solved, the more important might continue to be reported for a longer period of time, hence changing the characteristics of the sampled population of reported incidents)

3. It should be noted that classification as to Critical or Catastrophic does not always indicate a "deficiency," because some operations can never be rendered entirely "safe."

4. The system safety criticality rating would differ from other ratings such as those which might emphasize system effectiveness as an objective. For example, a specific failure which is easily detected and safe might require considerable time to remove and replace. While the lengthy time delay might significantly decrease system availability and effectiveness, it has negligible safety consequences.

PART 2. TEST REPORTS

A system safety criticality evaluation was made of rocket engine test incidents that were found to be not included in the failure reporting system. The incidents were found in various reports of discrepancies occurring before, during, or after the R&D firing of a large rocket engine system. The criticality evaluation was made in accordance with the definitions utilized in Part 1. The reports evaluated were made by personnel other than human factors, safety, or reliability engineers. All incidents occurred during 1962.

The evaluation was made of a different type of data, relating to another different engine system; roughly the same distribution was obtained (compare Table 4 with Table 1). In all four cases, over half of the reports involved a situation which was of a potentially hazardous nature. However, caution should be used in interpreting these results because of the assumptions and limitations of the classificatory process (Table 4).

It can be concluded that surveillance of data on reports which are, for various reasons, not included in a formal failure reporting system could yield worthwhile supplemental information upon which to base system safety investigations and analyses. It can also be concluded that problem reports initiated by personnel located in different geographical locations, working on different rocket engine systems, tend to report difficulties which have roughly the same proportional magnitude of system implications. It appears that evaluations of potential hazards, which at first seem fraught with subjectivism, have sufficient objectivity to be useful.

TABLE 4

SYSTEM SAFETY CRITICALITY EVALUATION OF
TEST OBSERVER REPORTS
(Rater D)

Classification	N	Percentage
Safe	18	46.1
Marginal	15	38.5
Critical	6	15.4
Catastrophic	0	0.0
	39	100.0

NOTE: Engine system is different from the three engine systems shown in Table

PART 3. PROTECTIVE EQUIPMENT (FOR HANDLING HAZARDOUS MATERIALS)

A recent study was made of the hazards present in handling Atlas ignition devices (hypergolic igniters, protechnic initiators and igniters, and solid propellant gas generators).* Of particular interest in this study was the use of protective equipment during the handling of Atlas ignition devices. A previous report had furnished a list of protective equipment similar to that used during research, development, and manufacture of hypergolic igniters.** This list was compared to lists of protective equipment found to be in use at various Atlas sites by Rocketdyne field service representatives. A review was made of all reported accidents and incidents that occurred during handling of Atlas ignition devices. A further analysis was made of potential fire, explosive, toxic, and work area layout hazards relative to the operational sites. The study indicated these results:

1. Some Rocketdyne callouts did not appear in the integrated technical manual (e.g., deerskin gloves).
2. Some technical manual callouts were not available at particular bases (e.g., synthetic rubber gloves).
3. No safety equipment was used for certain operations because of difficulty in moving about or handling the tools and missile explosives while wearing protective clothing (e.g., during installation of the SPGG's).

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* R-3621, Evaluation of Hazards and Preliminary Design of Protective Equipment for Handling Atlas Ignition Devices, Rocketdyne, a Division of North American Aviation, Inc., Canoga Park, California, 18 June 1962.

** R-3066, Hypergol Cartridge Maintenance and Storage, Rocketdyne, a Division of North American Aviation, Inc., Canoga Park, California, 13 July 1961

It was concluded that:

1. The protective clothing items listed in Air Force T.O. 21SM65E-2FJ-7-2 have proved unsatisfactory for application to the handling operations encountered at the operational sites.
2. The substitution of items better adapted to particular site requirements has resulted in unstandardized, varied equipment lists to perform similar tests at different sites.
3. This situation resulted "from the fact that the original equipment list supplied by Rocketdyne was applicable to research and development operations on which it was used, but is very unsatisfactory for use under operational conditions".

Recommendations were made relative to the design and use of improved protective clothing.

PART 4. PERSONNEL PERFORMANCE GUIDES

One of the principal factors in preventing personnel and procedural errors which could have catastrophic consequences, is the proper use of job performance guides (i.e., job manuals or operation and maintenance check lists). It is pertinent, therefore, to determine the accuracy of such technical data and the manner in which they may be used.

VERIFICATION DIFFICULTIES

A detailed study was made of two MA-3 technical manuals for accuracy, clarity, and usefulness as personnel performance guides and authoritative reference documents. This study, conducted at the Rocketdyne Van Nuys OSTF-1 EMA facility (October 1960 to June 1961) indicated that even good technical publications could be significantly improved in relation to the criterion of operational effectiveness. The results of these evaluations, the results of a technical manual verification process study, and some of the specific human factors recommendations which were made were included in a special report.*

The following statement, taken from that report, indicates some of the difficulties inherent in the technical manual verification process.

> "Ample opportunities to verify, update, and change the manuals before OSTF verification can be seen. Many changes and improvements were made, but, despite these opportunities and resultant changes, more than half the technical manual pages required some OSTF change, and each page required an average of five or more changes. Many, perhaps most, of these changes were minor or non-significant; any categorization as to significance, however, depends on individual, subjective judgment which varies as to the role, need, or perspective of the person making the judgment. Conclusion can certainly

*Peters, G.A., F.S. Hall, and C.A. Mitchell: Human Performance in the Atlas Engine Maintenance Area, ROM 2181-1002, 1 February 1962, 3-19, 215-224.

be drawn that one verification process would not be enough to permit placing faith in the accuracy and readability of technical manuals. In further support of this conclusion, it was found that during the EMA OSTF program three separate runthroughs were required for each manual to catch all changes required."

DEPENDENCE VS RELUCTANCE TO USE THE TECHNICAL DATA

The Peters, Hall, and Mitchell study also included a section on operator comments. Statements regarding the use of technical manuals were summarized as follows:

> "...relatively inexperienced SAC personnel ... have to rely almost entirely upon the directions given in the TO's, and, if the TO's are wrong, incomplete, or hard to understand, they really don't know what to do and may have to improvise or just do the best they can under the circumstances."

The study also stated:

> "Using personnel seemingly make only limited use of various technical data sources. They rely on general information or past experience or locally prepared material rather than use lengthy, hard-to-find, or elaborate procedures. They revert to the approach which requires the minimum of effort and inconvenience."

CAUSAL FACTORS

There are 65 Rocketdyne technical publications for just the MA-3 engine system. One of them, the overhaul technical manual entitled Rocket Engine Common Components, T.O. 2KA1-1-113, was issued as a new edition dated 21 March 1961. It was 2-7/8 inches thick and contained 1466 pages. Less than 7 months later, on 12 October 1961, a revision was issued which was 1-5/8 inches thick and contained over 800 pages. When replacement and new pages were added, there were 1526 pages in the revised manual.

Two months later, on 19 December 1961, another 3/4-inch-thick revision was issued, containing over 350 pages. The new total number of pages for this revised manual was 1,532 pages. While the size of this particular manual may not be typical, each of the 65 Rocketdyne publications does represent a considerable volume of technical information to be mastered by the user.

Many of the technical manuals are being constantly changed and re-issued at periodic intervals (i.e., every 90 or 180 days). Much of these data is site-peculiar (i.e., each geographical location has a somewhat unique system configuration). This imposes an added burden to those individuals who must learn and update their skills from such personnel performance guides.

In a recent Aerospace Support and Operations Meeting (held by the Institute of Aerospace Sciences at Orlando, Florida on 4 to 6 December 1961, B.J. Smith of GE-MSVD discussed what he called the "recent dissatisfaction with technical manuals for checkout and maintenance".*

He gave greater use as the reason for this dissatisfaction, saying that "it is unlikely that any missile manuals were less good than they had been for manned aircraft ... it is more likely that, with man out of the flight, he came to rely much more heavily on checkout and maintenance manuals than he had before." This greater use would probably have caused whatever shortcomings there may have been in technical manuals to be noticed and commented upon more frequently. While there may be greater use or reliance upon technical data in missile system operations, there are other factors which have served to focus attention on problems related to the development and use of technical manuals. One of these factors, already mentioned, may

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*Smith, B.J.: Achieving 0.9+ Human Reliability in Check-Out and Maintenance, Proceedings of the IAS Meeting on Aerospace Support and Operations (Unclassified Papers), 1961, 147-152.

be the sheer number and constant change of the technical manuals and technical support documentation which is used in a complex weapons system.

One approach toward the improvement of operational usage of technical data used to support or assure reliable human performance might be in the application of human factors principles and techniques to technical data generation, presentation, verification and validation, updating, and operational usage. For example, B. H. Manheimer and J. R. Kelley recently stated:

> "In the publications area there is an astonishing lack of application of human factors knowledge to the specification and preparation of instructional material--astonishing because of the large scope of the effort in terms of money and time expended, because of the importance of publications in proper maintenance, because of the known deficiencies in publications, and because of the obvious contributions that human factors information has made and can make in the area of written communication."*

SAFETY IMPLICATIONS IN THE USE OF TECHNICAL DATA

It is difficult to authoritatively document an unquestioned, unclassified, and direct relationship between the improper use of technical data and a catastrophic consequence. However, an illustrative case is available in the Civil Aeronautics Board Accident Investigation Report of the 17 September 1961 crash of Northwest Airlines' Lockheed Electra N 137US. The 37 fatalities of this crash were due to a missing safety wire. The report states:

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*(Manheimer, B. H. and Kelley, J. R. An Overview of Human Factors in Maintenance, IRE Transactions or Human Factors in Electronics, HFE-2, No. 2, September 1961, 73-78).

"Installation of the new aileron boost unit was performed by two mechanics on Shift 3 during the night of July 11-12. Testimony established that neither mechanic had followed the manual step by step, referring to it only when a problem was encountered, and that neither had read the removal instructions to determine what components had been unsafetied, disconnected, or rendered inoperative in the removal of the boost unit...

"The Board therefore concludes from the testimony that maintenance and inspection personnel showed an ignorance or disregard of published directives and instructions...

"The Board determines that the probable cause of this accident was a mechanical failure in the aileron primary control system due to an improper replacement of the aileron boost assembly, resulting in a loss of lateral control of the aircraft at an altitude too low to effect recovery." *

CURRENT ACTION

A "new concept in overhaul manuals" was announced in the Rocketdyne Service News (Vol.3, No. 9, September-October 1962), which stated that "the traditional concept of the organization and use of overhaul manuals has been changed considerably in recent months. These changes have been motivated by the field experience of our 'using' agency ... and by our <u>application of 'human engineering' techniques</u> to the rocket engine overhaul manuals."

Some of the changes are:

1. "Emphasis on the assembly of the engine in actual sequence rather than in an engine systems order"
2. "The supporting illustrations are now placed as near as possible to the text relating to them"

*<u>Aviation Week</u>, Vol. 77, No.26, 24 December 1962, 77-91

3. "The illustrations are designed to provide the technician with appropriate assembly details"

4. "New illustration sizes have been developed to provide more flexibility in page layout"

5. "Foldout illustrations are not used except for schematics and flow diagrams "

6. "Manuals are typeset and the pages are mocked up to coordinate text and illustrations closely"

"Two 'pilot' manuals incorporating these features are now being produced."

PART 5. SAFETY PROBLEMS ON THE ATLAS "F" SERIES

The following 30 safety problems (Table 5) were encountered during the early stages of Category II testing on the Atlas F Series at the OSTF-2 (silo) facility at Vandenberg AFB. These problems, affecting the reliability of the propulsion system, are listed (with references to the data reports which contain additional descriptive information). These problems provide supplemented support for the evaluations, conclusions, and recommendations contained in the following sections of this report.

TABLE 5

SAFETY PROBLEMS ON THE ATLAS F SERIES TESTING

Human Factors Problem (Identification No.)	Problem Description	Further Details May Be Found In The Following Reports
F-1	Rain incursion through silo doors soaks vernier engines, possible degrades V.E. reliability, and creates slippery working conditions for engine technicians	R-3569-1*
F-2	No safety barriers to work platforms 3D and 4D to prevent propulsion personnel from falling down silo	R-3569-1
F-3	Provisions missing for safe removal and storage of MGS pod fairing and B1 nacelle by MET/M	R-3569-1
F-4	Unsafe route used in SPGG removal which could cause this fragile solid propellant to be dropped	R-3569-1
F-5	Many difficulties and hazards associated with task of installing No. 2 vernier engine in MAB	R-3569-1
F-8	Lack of safety chains along access route to booster engines creates severe falling hazard for MET/M	R-3569-2
F-13	Using turbopumps and high-pressure propellant ducts for stepladders	R-3569-4,-7
F-18	No barricades, flashing lights, or warning signs were used during leak and functional tests using 1500 psi pneumatic pressure to G3077 test stand; visitors were unaware of dangers present	R-3569-4
F-19	Technicians were observed standing and and sitting on engine thrust chambers	R-3569-5

*See Appendix E for List of OSTF Reports

TABLE 5
(Continued)

Human Factors Problem (Identification No.)	Problem Description	Further Details May be Found In The Following Reports
F-25	Unsafe, "homemade" access ladder being used to reach thrust section of missile in raised position	R-3569-6
F-27	MET/M used thrust chamber hat band and aspirator as steps to enter thrust section and as work platform to stand on while working on engines	R-3569-9
F-28	MET/M used RX 20699-31 hypergol container shipping plug instead of 9010572 test plug to contain leak test (pneumatic) pressure	R-3569-6
F-29	G2000 service unit was left unattended during lunch period, with 440 volts power on, trich heaters on, facility GN_2 pressure applied, and low-pressure system pressurized to 90 psig	R-3569-6
F-30	G2000 was not properly secured at end of task; 110 psig was locked in high-pressure purge system	R-3569-6
F-35	Propulsion system tasks were especially hazardous because launcher refurbishment was not completed before missile was installed	R-3569-7,-8
F-36	No.1 booster engine hydraulic flow limit valve must be opened manually during turbopump preservation procedures and is inaccessible except by standing on B1 gimbal actuator outrigger struts	R-3569-7
F-37	Permanent platform in front of elevator at silo level 6A has no safety chains or guard rails at either end and is often crowded	R-3569-7
F-43	MET/M did not use safe access route to and from the work platform	R-3569-8

TABLE 5
(Continued)

Human Factors Problem (Identification No.)	Problem Description	Further Details May Be Found In The Following Reports
F-49	The MET/M's "work platform" while connecting electrical harnesses to RERB is extremely dangerous and tiring	R-3569-8
F-50	Personnel did not wear the prescribed safety equipment while installing missile pyrotechnics and hypergolics	R-3569-8,-9
F-51	No.1 vernier engine was hand carried to top of missile because sling could not be found	R-3569-9
F-52	MET/M failed to maintain LOX-clean condition when connecting vernier engine oxidizer lines	R-3569-9
F-53	Falling hazards were noted during missile ordnance removal tasks because safety rails were not installed on the launcher and the B-2 work platform	R-3569-9
F-54	Checklist manning was not followed, e.g., three men (instead of one) were used to remove igniters and initiators	R-3569-9
P-1	Silo work platforms, safety chains, and safety rails were not effective in producing safe task performance because of deficiencies in maintenance, organizational controls, and design	R-3569-10
P-3	Integrity of engine, missile and AGE hardware was jeopardized by deficiencies in maintenance, organizational controls, and equipment design	R-3569-10
P-7	Tasks were not performed: hardware and personnel were thereby exposed to unnecessary hazards	R-3569-10
P-18	MAB facility design permits personnel to injure themselves	R-3569-10
P-19	Personnel did not use safety equipment provided for their protection	R-3569-10

SECTION 4

DATA EVALUATION

Analysis and evaluation
derivation of principles,
and discussion of the
implications of the data

The two preceding sections presented various types of data relating to systems safety engineering. An attempt was made to discuss the implications of each specific incident or group of material presented. More can now be gained by a summary evaluation of the data. This section presents the results of a general analysis of the data, with emphasis on the derivation of principles useful in future design and development activities.

DATA EVALUATION

PART 1. DERIVATIVE HUMAN FACTORS DESIGN PRINCIPLES

The specific design changes needed to correct or ameliorate each system safety incident have been described in the preceding case studies. Implicit in the data are a number of human factors design principles which should be carefully reviewed and considered by engineers designing new equipment.

These principles offer some answer to two questions sometimes voiced by the design engineer: Why do people make such mistakes? How can these errors be eliminated? These problems are the type to which human engineers address themselves. However, if the design engineer is provided information concerning what actually does occur to his equipment in actual use, he can often solve the preventative question (what to do about it), by himself, for his particular design. This section therefore attempts to capsulize some of the human factors principles derived from the operational system test data. The information should be useful to designers of equipment, facilities, test instrumentation, procedures, and operations support material.

The following principles describe what actually does happen and how people actually deal with equipment in the field. It does not describe what should happen or what they are supposed to do. To correct for human factors difficulties, the design should be in terms of anticipated usage in the operational situation. Therefore, bearing the following principles in mind, the design engineer should strive to prevent or properly channel the undesirable aspects of human performance in relation to the item of equipment being designed.

THE 25 DESIGN PRINCIPLES

Principle 1

If insufficient or inadequate equipment is provided, equipment will be improvised or modified at the site in order to get the job done. Improvised equipment generally leads to improvised procedures. Improvised procedures often result in safety hazards (Human Factors Problems 57, 272, 290).

Principle 2

A weak excuse is enough for some people to do what they please. To do what they please is often to do what they should not do (Human Factors Problems 154, 211, 213, 230, 274, 276, 285, 291).

Principle 3

People often feel that "it can't happen here." They feel that other people at other locations may get hurt (or damage equipment) by disregarding instructions, but "not us." (Human Factors Problems 154, 168, 213, 223, 252, 288). Therefore, foolproof procedures are necessary where possible. Since procedures are based upon the design of equipment, it is the basic design which permits foolproof procedures to be developed.

Principle 4

Corrective action on a problem does not always mean the end of the problem. The action taken may not be sufficient, appropriate, or affect the real cause of the problem. It might not completely prevent it from recurring elsewhere or in some other way (Human Factors Problem 284).

Principle 5

No matter how simple and foolproof it looks on paper, try it before you buy it (Human Factors Problems 85, 129, 199, 235, 237, 262, 279).

Principle 6

If the implicit response of the equipment is wrong, it will eventually produce some wrong responses (Human Factors Problems 60, 111, 227).

Principle 7

A warning note in the appropriate technical manual usually will not overcome a safety problem; it is of only limited and supplementary value to reduce the probability of mishap. People may not have read, remembered, or even know where to find such warning notes.

Principle 8

Some people have to see equipment get damaged by inadequate task performance before they take their assignment seriously and do it thoroughly and carefully, (Human Factors Problems 231, 274, 288).

Principle 9

Do not rely upon special training for those who may use the equipment. Not all individuals will receive the "required" training. Some will have had outdated training, related training, or catch-as-catch-can training. Therefore, try to design for safety rather than hope for special safety training.

Principle 10

Some people have to see someone get hurt before they will believe the practice is dangerous (Human Factors Problems 168, 274).

Principle 11

People sometimes prefer to work under hazardous conditions, as if their bravery makes the job more important (Human Factors Problems 98, 103, 129, 216, 235, 255, 272).

Principle 12

Tell some people "don't" and they do, notwithstanding the magnitude of personal risk. Instructions alone are not enough to guarantee proper care, operation, and safety (Human Factors Problems 154, 168, 211, 216, 221, 223, 243, 252, 274).

Principle 13

Expect that the equipment will be used in the wrong way. Study the consequences of doing the job incorrectly. Then design the equipment so that incorrect operation will do minimal damage.

Principle 14

Will the technician damage it or injure himself if he does not know what it is? Be sure that full, understandable, and legible identification is provided (Human Factors Problems 71, 86).

Principle 15

Bad conditions which are condoned often seem to multiply and interact to produce serious safety problems (Human Factors Problems 216, 248, 272, 291).

Principle 16

People tend to avoid or eliminate continual sources of difficulty, not always by sensible or logical approaches (Human Factors Problems 57, 211, 272, 274).

Principle 17

Just as development engineers work the "bugs" out of critical equipment, so must others work the "bugs" out of the task performances of each person assigned to critical tasks. This may be done, for example, by tutoring them as they practice on nonhazardous simulators or inerts (Human Factors Problems 227, 288). A certain amount of on-the-job training takes place using operational equipment. Mistakes will be made by these partially trained personnel. The original design of the equipment must anticipate such usage and mistakes.

Principle 18

If the designer does not know all of the requirements of the equipment, it is not likely that his design will meet all of them (Human Factors Problem 236).

Principle 19

In the midst of complex, multimillion-dollar items of equipment, an item of inexpensive and simple construction may seem unimportant, and its use or maintenance may be neglected (Human Factors Problems 276, 291).

Principle 20

Unfortunately, people must be protected from themselves. Each leadman, stand talker, and/or safety committeeman must be responsible for certain areas of personnel and equipment safety. An extremely important part of this responsibility is combatting foolish shortcuts and deviations from the prescribed procedures (Human Factors Problems 16, 98, 121, 154, 166, 168, 206, 211, 213, 216, 223, 248, 274, 285, 288, 302).

Principle 21

Abbreviated checklists are good only when the detailed procedures are known. It is difficult to get technicians to leave a checklist and consult the detailed job procedures when they encounter an unfamiliar area (Human Factors Problems 111, 199). When in doubt, people tend to experiment and fill in the gaps themselves.

Principle 22

Reputations of equipment are important (Human Factors Problems 86, 88, 291). If there is even a rumor of hazard or difficulty, task performance and use of the equipment may be adversely affected.

Principle 23

An item of equipment which is difficult to maintain may not be kept in a condition to be used when needed. Equipment which is difficult to use will not be used if any substitute is available.

Principle 24

If the equipment is designed in such a way as to be dependent upon communications between crew members, it is susceptible to human error. People are seldom able to recognize that they have not communicated sufficiently until mistakes have been made, and sometimes not even then (Human Factors Problems 121, 166, 288).

Principle 25

In summary, the designer should remember that most of the reliability problems affecting operational equipment did not represent defects in the equipment itself, but defects in the way in which it was used. To count upon any significant differences in treatment of equipment on future programs may constitute a form of wishful thinking. It is much better that the worst problems are precluded because of original design than to grapple with them after designs are relatively frozen.

PART 2. DESIGN IMPLICATIONS

The case studies, and other data, have provided examples which indicate that equipment of a perfectly good design sometimes fails to do its job because of something the designer had no control over, didn't think of, or had no way of anticipating. Some of these problems could have been prevented if the following suggestions were known, made available, and utilized by the design engineers in the design of equipment for human use.

RESTRICT PROCEDURAL ALTERNATIVES

There is only one way to get people consistently to do a thing the right way: make it impossible to do it any other way. Since this is not always possible, several approaches are listed that can be used to get people to do things the desired way more consistently:

1. Sometimes the right way can be made the easiest way.

   EXAMPLES: Human Factors Problem 57: Adapter Identification

   Human Factors Problem 206: Stepping on Electrical Cables

   Human Factors Problem 216: Using Turbopumps for Stepladder

2. Sometimes the wrong way can be made the most difficult.

   EXAMPLE: Human Factors Problem 121: Communications Needed

3. Clearcut guide lines can be established on what can be done safely.

   EXAMPLE: Human Factors Problem 290:
   NCU Line 3 vs Line 4

4. Planning could include every location where the task would ever be performed.

   EXAMPLE: Human Factors Problem 284:
   Interference with Sustainer Hypergol Cartridge

5. The wrong way could be made unpopular (and the right way popular).

   EXAMPLE: Human Factors Problem 243:
   Are Hard Hats Okay?

6. For some tasks, continual reminders may be necessary from a safety committeeman, leadman, or stand talker.

   EXAMPLE: Human Factors Problem 248:
   Blocked Safety Aisles

7. Organization Controls could be used to direct and strictly enforce the use of the right procedure and prohibit use of wrong practices.

   EXAMPLE: Human Factors Problems 98, 154, 168, 211, 216, 223.

8. Identify the specific people who will have clearly defined responsibility for the integrity of the equipment and the safety of the people for stated period of time.

   EXAMPLES: Human Factors Problem 121:
   Commication Needed

   Human Factors Problem 168:
   High-Pressure Hose Tiedown

Human Factors Problem 206:
Stepping on Electrical Cables

Human Factors Problem 211:
Thrust Chamber Pad Not Used

Human Factors Problem 231:
Pregimbaling Precautions

Human Factors Problem 248:
Blocked Safety Aisles

9. Provision could be made for continued orientation, indoctrination, or education concerning the dangers or faults of improper practices, as contrasted with virtues of the right way.

EXAMPLES: Human Factors Problem 98:
Standing on Thrust Chambers

Human Factors Problem 168:
High-Pressure Hose Tiedown

Human Factors Problem 211:
Thrust Chamber Pad Not Used

Human Factors Problem 216:
Using Turbopump for Stepladders

Human Factors Problem 111:
Inflating Throat Plug Tire

Human Factors Problem 121:
Communication Needed

Human Factors Problem 154:
Cleaning with Trichloroethylene

Human Factors Problem 166:
Neglecting to Use Communications System

Human Factors Problem 223:
Human Pack Horse

DESIGN FOR MINIMUM PERSONNEL

"One is easy, two is hard, and three is almost impossible." This is what service personnel consistently reply when asked if they can get a helper for a few seconds to assist in removing covers, erecting access ladders, or positioning platforms. If an item of equipment has to be lifted or opened and is large or heavy:

1. Counterbalance it
2. Hinge it
3. Build it in sections
4. Attach lifting eyes for crane hooks

Do something so that one or two people could handle it. Do not rely or be dependent upon having a lifting sling to go with it because the sling may be cut out of the budget or not available at all locations. Do not tell yourself that they will always have plenty of extra people standing around because, even if this were so, having them and getting them to lift your equipment are two entirely different things.

EXAMPLE: Human Factors Problem 221:
Hoisting Vernier Engine Maintenance Platform

ANTICIPATE ROUGH USAGE

If your equipment is large, fairly strong, somewhat flat on top, and located near areas where people will be trying to work, you can be assured that some of them will sooner or later sit on it, stand on it, jump on it, lay or drop tools on it, etc. If your equipment is rugged enough to take all this, well and good. If not, see what you can do about ruggedizing it, or getting some good maintenance platforms provisioned, or putting some protective covers on it that will take all this abuse. Do not mislead yourself that stencilling NO STEP on it will do the trick. Neither will complaints, directives, and detailed instructions. Prepare for the worst, anticipate rough usage, and design accordingly.

EXAMPLE: Human Factors Problem 98:
Standing on Thrust Chambers,

Human Factors Problem 216:
Using Turbopump for Stepladders.

UNAMBIGUOUS IDENTIFICATION

The addition of appropriate panel nomenclature to clearly and unambiguously identify switches, lights, gages, regulators, valves, etc., is a major step forward in aiding operators and repairmen. But careless use is a major step backward. After assignment of proper nomenclature to the components on the control panel or other location, back away and take a second look to be sure that each component really is what the nomenclature says it is. For example, do not identify a switch or a light as MAIN POWER unless it really is tied to the main power. Be careful with abbreviations. They are often ambiguous, e.g., REG might stand for regulator, regulated, regulating, registered, regular, etc. Be sure to ask yourself: is it what it says it is?

EXAMPLE: Human Factors Problem 60:
Shock Hazard

DESIGN TO ELIMINATE SUPPORT ITEMS WHICH MAY NOT BE USED

Consider what would happen if the customer does not use a particular item of equipment. Would or could the consequences be serious? If so, either design to ensure that they will use it or eliminate the need for it. For example, you can be sure they will use your thrust chamber throat plug (they can not perform leak checks without it). But you cannot be sure they will use a thrust chamber protective pad, because they can step on the bare chamber while installing and removing the throat plug. Therefore, it would be better to forget the pad altogether and design the plug long enough and light enough to be installed from the outside (also design it, if possible, so it is not necessary to use lubricants or other compounds which must be wiped off the chamber walls when through).

EXAMPLE: Human Factors Problem 211:
Thrust Chamber Pad Not Used

Another example of the same principle: either make shipping covers so fragile that they cannot be used for test plates, or make them rugged enough to double for test plates (and forget about provisioning test plates).

EXAMPLE: Human Factors Problem 274:
Shipping Covers vs Test Plates

MAKE IDENTIFICATION OF PARTS OBVIOUS

Many checkout operations use quantities of standard fittings and hardware which are obtained from local stock and returned when tasks are completed.

If you supply special adapters with your equipment and they are made from what looks like standard fittings and hardware (no special identification), your adapters will also get "returned" to stock, or put in some other adapter set (where they cannot be found when needed).

EXAMPLE: Human Factors Problem 57:
Adapter Identification

DO NOT HIDE FITTINGS

If the item of equipment has to be placed inside something else, do not put some of the connections or fittings the technician has to reach up inside and some out where they are easily reached (unless the symmetry or other features make the presence of the inside connections very obvious). Otherwise, the technician will try to connect to the near fittings when he should be using the hidden or distant fittings.

EXAMPLE: Human Factors Problem 111:
Inflating Throat Plug Tire

DESIGN BY TASK RATHER THAN BY COOKBOOK DATA

When using standard human engineering data from textbooks, handbooks, or other data sources, be sure that the task to be performed is similar to that upon which the data were based. For example, data on access door dimensions could be misleading if based strictly upon anthropometric data which are expressed in terms of minimum permissible dimensions. The turbine spinner access door opening is 12 inches square, which is adequate for maintenance tasks involving reaching in simultaneously with both hands, for distances less than 12 inches (according to some standard human engineering references). There are exceptions to every rule, and this is one. The solid propellant gas generator is too heavy. The technician who tries to remove or install it through the access door provided will almost invariably smash or pinch a finger and drop the SPGG. When using standard dimensions, be sure the task is not the exception to the rule. When in doubt, leave a little extra room.

EXAMPLE: Human Factors Problem 227:
Dropping Solid Propellant Gas Generators

PART 3. SUPPLEMENTAL CHECKLIST MATERIALS

The design principles and design implications just described can be supplemented quite easily by reviewing the specific design principles already available in various design checklists. There are many compilations of such design checklists which contain special safety sections. A few representative checklist references are described below for the interested reader.

1. Greek, D.C.: Checklist of Human Engineering Design Principles, MD 58-334, Missile Division, North American Aviation, Inc., Downey, California, January 1959. This publication contains seven sections, one of which deals with safety. The safety section contains questions relating to materials, fire and explosive protection, protection against corrosive agents, protection from mechanical hazards, and electrical safety.

2. Arnsfield, P. J.: Human Engineering Maintenance Design Criteria: AIR-345-61-IR-139 (DAC Report No. SM-38686), Prepared for Douglas Aircraft Co., Santa Monica, California by American Institute for Research, Los Angeles, California, January 1961. This human engineering design checklist contains 86 pages of items. These items are supposed to be reviewed by the designer who circles, as appropriate, "NA" (not applicable), "Y" (yes), or "N" (not incorporated). Each question is coded as to five kinds of effects or consequences. Two of the five consequences relate directly to safety: MT, Maintenance Time; ME, Maintenance Error; LO, Logistics; ED, Equipment Damage; and PI, Personnel Injury.

3. Designer's Checklist for Improving Maintainability, ASD-TDR-62-45 (AD 275 889), Wright-Patterson Air Force Base, Ohio, February 1962. This publication contains 12 general design categories, including one on "Safety, Damage and Interference." Out of a total of 327 checklist items, the safety category contains 37 design suggestions.

4. Folley, J. D. (Editor): Human Factors Methods for Systems Design, AIR-290-60-FR-225, American Institute for Research, Pittsburgh, Pennsylvania, 1960. Chapter 4, "Detection of Error Producing Designs," by R. L. Weislogel, contains a section on checklists and evaluation guides (with some sample items) to identify error producing designs.

5. Peters, G. A., F. S. Hall, and C. A. Mitchell: Human Performance in the Atlas Engine Maintenance Area, ROM 2181-1002 (also see R-3520), Rocketdyne Reliability Engineering, Canoga Park, California, 1 February 1962. This publication contains a section evaluating a human engineering checklist (containing a Safety and Hazards section), a task evaluation checklist (containing a Safety section), an equipment evaluation checklist (containing a Safety section), and a posttest interview questionnaire (containing a Safety section). For system testing, it was concluded that checklists were useful for the initial guidance and training of observer/interviewers, but were not suitable as test-and-evaluation management control devices.

PART 4. GENERALITY OF THE FINDINGS

The Case Study and Supplemental Data sections contain a great deal of highly specific detail information. The question often arises whether such data are so "situation specific" that generalizations cannot be validly made to other situations, projects, or efforts. If such a belief were completely true, it would probably preclude or negate the worth of <u>any</u> consideration of field data because of the following reasons:

1. Despite efforts at standardization, any particular field situation is only an approximation of some theoretically ideal or "representative" operational situation. That is, no perfect situation could probably ever be found in which to collect truly representative data.
2. If it were possible to obtain system development data under experimental conditions (i.e., with clear definition and full replicable control over all variables), the rigidly controlled conditions required would create an extremely artificial, "nonrepresentative" situation. That is, perfect experimental data probably would not be valid for the purposes of this report.
3. In relatively new areas of investigation such as this area of human performance research, there is only a limited fund of directly applicable and useful knowledge available from related areas of activity. This makes it extremely difficult to render judgment as to what is or is not situation specific and what has or has not some communality of characteristics with other situations. Therefore, it would seem highly desirable that empirical data, <u>gathered under known conditions</u>, be closely

examined in order to organize or generate some logical group of assumptions which would permit the formulation or deduction of verifiable or testable hypotheses. This is the only logical approach toward developing useful operating principles or tentative guides for decision.

When examining various human factors problems, some problems appear to stand by themselves as "important" while others seem quite trivial and of minor import. However, the cumulative effect of a series of minor problems may markedly influence the manner in which some job operations are finally accomplished. So it is of some importance that attention be directed to the resolution of seemingly minor, highly specific, problems as well as to the more critical or major problem areas in a complex man-machine system.

In order to encourage the discovery of communuality of characteristics between discrete events or incidents, this report contains

1. A grouping of incidents into logical problem areas
2. A cross referencing between various problems and incidents
3. An elaboration of system implications and the corrective action process
4. An introduction of pertinent supplemental data from related sources
5. A presentation of appropriate background material and reference to the matrix of related system development activities

It is felt, therefore, that there is sufficient generality in the findings of this report to warrant its careful review and study by individuals responsible for the design and development of similar systems even though the performance specifications, intended use, and basic configuration may be different. This presentation of information is basically intended as a stimulus and guide to actions which could more efficiently, quickly, and effectively resolve or prevent the occurrence of system development difficulties previously experienced. However, the material should be considered as part of a working paper which would necessarily be subject to revision or extension as needs are evidenced or state-of-the-art refinements are evolved.

PART 5. HUMAN ERROR PRINCIPLES

An examination of the experiences which have resulted from the human error investigation, analysis, and corrective action process has permitted the formulation of 10 tentative "principles," generalizations, or guides for those attempting to understand the nature of the human error investigation process.

Principle 1

You can trust your knowledge of a human-initiated failure to the degree to which you are able to make a first-hand investigation of all of the facts in the case. A corollary principle to this is that upon investigation a human factors engineer (i.e., a human error "detective") will usually see a problem quite differently than it is originally reported because his perspective (or what he is trained to look for) is different.

Principle 2.

There usually is no one simple solution to human error problems; it is more typical to find that there are multiple corrective actions required. In tracing back the causes which led up to or permitted the error to occur, it is more typical to find that there are a series of branching preventive measures which are desirable to help preclude the recurrence of such difficulty.

Principle 3

Beware of general solutions to classes of problems. Dramatic solutions to big problems are rare and usually misleading. There is much more assurance of constructive action when specific problems are analyzed in a specific fashion and when sufficient effort is budgeted for follow-through to ensure the attainment of a satisfactory remedy.

Principle 4

People do not always act as they are supposed to, as they have been instructed or directed, or as you might suppose that they would or should. Hence, equipment and procedures have to be adapted (and readapted) to reduce or prevent the intrusion of unwanted human variability during periods of inadequate organizational control, work stress, and the typical operational handicaps which have to be expected on the basis of past experience.

Principle 5

Intelligent workers can "beat any system" of arbitrary or paperwork controls which might create some difficulty or unpleasantness for them or which seeks to impose upon them what they feel are unrealistic requirements.

Principle 6

A flood of previously unreported incidents could result as people hear more about human error, become sensitive to it, and suffer no personal repercussions as a result of reporting it; this new information could easily change the ascribed causes of some chronically recurring problems.

Principle 7

Avoid attempting to utilize figures-of-merit based upon human error to rate equipment items or attempting to use human error percentages as an index of workmanship, craftsmanship, or morale. Any comparative rating scheme will unfavorably influence opportunities to gain or evaluate information and will hinder negotiation for corrective action.

Principle 8

Superficial corrective action, such as the "notification of responsible supervision" or "re-emphasis" of existing regulations, generally appears helpful in the absence of any other course of action. However, it should be recognized that habitual response of this type may be inadequate and that it sometimes does more harm than help.

Principle 9

Do not ignore minor, trifling, nuisance, or marginal problems. They often serve as fruitful leads to significant problems.

Principle 10

Direct observation of actual working conditions is critically important to determine the true nature of the situation under study, to locate significant unreported or unrecognized problems, and to determine what could be an effective remedy. Analysis, theory, logic, and hypothetical assumptions are no substitute for direct observation.

Additional information regarding the current need to reduce human error, the contractual requirements for this activity, and some of the techniques for the implementation of a program to reduce human error may be found in Section 5, Part 1, Human Error and Goofproofing, and Section 6, Part 1, Identification of Human Error.

SECTION 5

PERSPECTIVE

General information on the background, context, and approach of safety engineering.

The preceding section is an analysis of systems safety engineering data, its evaluation relative to the variables of an operational system, and the implications relative to various design and development activities. This section presents general background information for a clearer understanding of the approaches involved in achieving safety design objectives during system design and development.

PERSPECTIVE

PART 1. HUMAN ERROR AND GOOFPROOFING

WHAT IS HUMAN ERROR?

Human error is defined in AFBM Exhibit 58-10 (Reliability Program for Ballistic Missile and Space Systems) in terms of "human-initiated failure," i.e., "any system failure, the cause of which is traceable principally to a faulty human act or actions (either of omission or commission)," and includes "such things as incorrect wiring, rough handling, incorrect adjustments, activation of wrong control, etc." This 1959 Air Force exhibit also went on to state that "all human-initiated failures will be identified and will be reviewed by specialists in human factors."

We could define human error as "any deviation from a previously established, required, or expected standard of human performance that results in an unwanted or undesirable time delay, difficulty, problem, incident, malfunction or failure."

Some human errors are straightforward and simple as to their identification and their cause, but the vast majority of human errors only appear to have simple causation and corrective action remedies. In regard to corrective action, for example, reports of excessive human error could be termed a manifestation of personnel carelessness and indifference that should be corrected by greater detailing and enforcement of procedures, or by more discipline and "running a tighter ship." Such simple solutions may appear effective as the reported malfunctions or difficulties decline. However, the case may be more apparent than real if the difficulties are just not reported or are not openly discussed, i.e., if the campaign to "do better" merely restricts, screens, masks, or recategorizes the same recurring problems. This is but a variation of the general principle that intelligent workers can "beat any system" of arbitrary or paperwork controls which might create some difficulty or unpleasantness for them, or which seeks to impose upon them what they feel are unrealistic requirements.

Some other immediate, but self-defeating, corrective action alternatives are the passive or essentially nonaction-oriented responses, such as the following:

1. "People are not perfect"
2. "We need better people"
3. "We are doing the best we can under the circumstances"
4. "Our real difficulty is caused by that other (department, process, or supplier)"

Unfortunately, if we fail to systematically attempt to reduce human error as we gradually reduce or eliminate all the other sources of product unreliability or error variance, it means that human error can only loom proportionally greater and greater as a residual uncontrolled error variance. Eventually, this problem of human error must be realized, and a positive plan of action undertaken to find relief or control. At this point, another general principle takes effect. As people hear more about human error and become sensitive to it, more of it is reported. If no personal repercussions result, it may well open a floodgate of previously unreported incidents, and it could easily change the perception as to actual causative factors underlying some chronic malfunctions, failures, incidents, or difficulties. For example, a continuing component design difficulty may actually be the inadvertent result of some seemingly minor upstream procedural difficulty during test operations.

If we are truly interested in improving our product reliability and lowering redesign and rework costs, any increased and broadened flow of meaningful information will provide an excellent opportunity for constructive action.

RECENT SPECIFICATIONS

The actual extent of human error and its resultant costs, in terms of production dollars and operational capability, has been widely discussed and is well known to those who work close to the physical hardware of almost any large man/machine system during its system development stages. It is explicitly recognized in the missile and space system requirements for organized human factors efforts which have been published by NASA and various military agencies during the past year.

The April 1962 edition of NASA Quality Publication NPC 200-2, <u>Quality Program Provisions for Space Systems Contractors</u>, contains the following statement (paragraph 14.3c) dealing with Corrective Action:

> "Analysis of malfunctions, troubles, and failures traceable to human or operator error shall be made by persons skilled in human factors engineering."

The October 1961 edition of the Air Force military specification MIL-R-27542, <u>Reliability Program Requirements for Aerospace Systems, Subsystems, and Equipment</u>, contains the following statement (paragraph 3.1f):

> "A factor in systems reliability is human reliability which includes the extent to which the equipment has been human engineered to minimize human error in the manufacture, test, operation, and maintenance of the system."

This same reliability specification also states (paragraph 3.5.3):

> "The reliability program shall apply the principles of human engineering in all operations during the manufacture, test, maintenance, and operation of the system or subsystem where personnel are involved."

In February 1962, AF BSD 61-99 was issued as Human Engineering: General Specification for the Development of Air Force Ballistic Missile Systems. It contained a broad outline of the activities necessary for effecting an integrated human engineering effort, including the information submittals thought necessary to effect a positive management control of these activities during system development. It emphasized the need for human engineering participation in systems analysis, detail design, and system test and evaluation.

The July 1962 edition of the Handbook of Instructions for Aerospace Personnel Subsystem Designers was issued by the Air Force Systems Command as AFSCM 80-3. This document contains over 200 pages describing the means by which human factors may be considered during each stage of system development. The emphasis was on system requirements, design engineering, and operational support activities. The equally critical areas of inplant test, fabrication, assembly, and inspection are covered only in a cursory fashion.

BASIC REQUIREMENTS

The very fact that these and other requirements have been issued is prima facie evidence that there is a fairly widespread recognition of the need for the reduction of human error and for an organized, systematic approach to the problem.

Such specifications or requirements usually involve the following five considerations:

1. Separate, identifiable, and specialized analytic activities should be established to deal with human error (i.e., it is not just "another hat" to be worn by other activities; although unique organizational needs and talents may dictate that various combinations of existing functions might best perform some of the technical requirements of a particular program).
2. Such activities should emphasize corrective or preventive action (i.e., tabulations of the extent of human error may make people aware of the problem, but they do not change the situation).
3. This effort should deal with all stages of system development and all product-oriented functions within a company (i.e., it should not be entirely a design engineering function).
4. Specialists in human factors engineering are required to perform such specialized services and, quite often, requests to bid specifically ask that the human factors engineers be listed by name in the proposal. Obviously, properly qualified* and trained individuals are needed--if you can find them. One more note of caution: human error has absolutely no direct relation to current time-and-motion work, current industrial psychology, or current industrial engineering.

*Qualified by virtue of basic academic coursework in the engineering and behavioral sciences, supplemented by special training courses in human factors engineering, followed by properly supervised or tutorial work experiences in human factors engineering. Specialization in this work area is usually evidenced by affiliation with the appropriate professional sections of various technical and scientific societies, contributions to the technical literature, and some professional stature or recognition in the field.

5. Broad outlines as to effective human factors programs are often provided, and, in some cases, extremely detailed analytic efforts in certain restricted areas are described (i.e., there are established and effective techniques for certain aspects of this type of activity).

OPERATIONAL DEFINITION OF HUMAN ERROR

Several standard definitions of the terms "human error" and "human-initiated failure" have been presented (Section 5, Part 1; Appendix A, Glossary). The authors also presented a general definition of human error: "any deviation from a previously established, required, or expected standard of human performance that results in an unwanted or undesirable time delay, difficulty, problem, incident, malfunction, or failure."

This general definition may be employed in a wide variety of activities, e.g., the categorization of human-initiated failures in a failure-reporting data system, the identification of human error in a manufacturing inspection procedural audit, the tabulation of the dependent variable in a simulation test, or the initiation of a deviation/difficulty observer report in an operational system test situation.

When attempting to utilize any general definition in a specific situation, some further explanation and elaboration of classification criteria are often necessary. In its application to the categorization of failure data, the definition appears clear and concise until someone conscientiously attempts to classify all failure reports into one of the two implied categories (human-initiated failure and nonhuman-initiated failure). At this point, it is discovered that all failures could be considered as human-initiated if the cause is traced back far enough. For example, a valve shaft may have failed because a supplier design engineer selected an inadequate material specification.

In order to differentiate or segregate the data into a set of meaningful categories, it is necessary to know the purpose of such a tabulation and the specific use which will be made of such a categorization. It would be meaningless to classify almost every failure as being human-initiated; another breakdown of such data would then be necessary in order to have meaningful trend or appropriate information for investigation (i.e., corrective action) purposes.

Therefore, for practical purposes, it is wise to restrict the standard of human performance to the behavior standard established for the particular area or set of activities under study in which corrective action is contemplated or considered feasible. For example, one study might consider as human error only the errors of personnel assigned to a particular test site who directly or indirectly affect the operation of the particular activity being investigated. Another study might consider only the errors committed by manufacturing personnel (machinists, inspectors, planners, material handling personnel, etc.), but would exclude the errors committed by vendor, purchasing, engineering design, and other personnel as being outside the realm of that particular study.

For the purposes of operational system testing, the "standard of human performance" is any accepted, established template of expected behavior, which is detailed and documented prior to a test exercise, e.g., the personnel performance checklist.

For the purposes of simulation testing, the "standard of human performance" is explicitly recognized in the statements of the hypothesis being tested and the definition of the measurements to be taken of the dependent variable in the experimental design.

The basic question "How may we identify and control sources of human error that might affect the design, development, fabrication, test, and operational reliability of complex systems?" is discussed at further length in Section 4, Part 5, under Human Error Principles, and in Section 6, Part 1, under Identification of Human Error.

PART 2. REQUIREMENTS FOR A SAFETY EVALUATION

There have been a number of separate requirements for an evaluation of missile systems relative to safety criteria. Several are described in the following paragraphs and serve to illustrate the nature of such requirements. Recently, several versions of AFBSD Exhibit 62-41 dealing with System Safety Engineering have been distributed for review and coordination preparatory to the issuance of a military specification covering the system safety engineering area. Additional emphasis has also been given safety in man-rated reliability formulations. Because of current interest in this area, it can be anticipated that future requirements for detailed safety evaluations will, most likely, be increased rather than de-emphasized.

ORIGINAL DESIGN REQUIREMENT

There were a number of requirements to incorporate safety features into the design and development of Atlas equipment and procedures. For example, the military standard on Human Engineering Criteria for Aircraft, Missile, and Space Systems, Ground Support Equipment: (MIL-STD-803 (USAF), 5 November 1959), contains a section on "Hazards and Safety." This military standard also references various other applicable regulations, standards, specifications, technical reports, and handbooks that deal, in part, with the safety design criteria.

GENERAL PERSONNEL SUBSYSTEM TEST REQUIREMENT

The general requirement for a safety objective during system test and evaluation may be found in AFBMD Exhibit 60-1*. One of the test objectives

*AFBMD Exhibit 60-1, Personnel Subsystem Testing for Ballistic Missile and Space Systems, 22 April 1960.

(paragraph 3.6.1, Human Engineering) is the "identification of design features or procedures which constitute a hazard to safety of personnel or equipment."

CATEGORY II TEST REQUIREMENT

The detailed safety test objectives for a Category II test program were specified under paragraph IV g, Safety, in AFR 80-14.* The test objectives are:

1. "Determine whether all hazardous operations are properly identified, controlled, and conducted."
2. "Determine whether hardware design, safety equipment, or procedures of sequencing of operations impose a hazard to safety of personnel."
3. "Determine whether weapon system checkout can be performed safely under the operational system."
4. "Determine whether propellant loading (liquid systems) and countdowns can be safely performed."
5. "Determine whether maintenance of the weapon system in a standby readiness condition can be safely performed."
6. "Determine whether proper and adequate protective clothing and equipment are specified for use during hazardous operations."
7. "Determine whether safety distance criteria specified for hazardous operations are adequate and do not hinder operational procedures."

*AFR 80-14, Category II Test Program Plan for Ballistic Missiles, 13 April 1961.

8. "Determine whether hazard-detecting devices are adequate and properly detect hazards they are to monitor."
9. "Determine toxicity implications and establish and document adequate safety precautions."

OSTF TEST PLAN REQUIREMENT

Specific safety evaluation requirements for the OSTF-1 VAFB test and evaluation program were outlined in a test plan* prepared with the participation and coordination of all Atlas associate contractors, ATC, and AFBMD.

1. Paragraph 5.0, PSS Activities to be Performed During Part I: "(h) Review of procedures for use and handling of explosives and hazardous equipment."
2. Paragraph 6.0, PSS Objectives for Part II OSTF: "(a) Equipment Design. Human design considerations relative to maintainability, operability, communications (loads), reliability, and safety"
3. Paragraph 8.1.1, Data Sources: "8.1.1.2..........the checklist shall contain provisions to gather information on.............
   d. Safety Hazards"

*GM 6300.5-1060, Integrated Test Plan for WS-107A-1 Operational System Test Facility OSTF No. 1 and No. 2. Supplement: Personnel Subsystem Test Plan Annex, 15 December 1960.

PART 3. GENERAL SAFETY FUNCTIONS

RELATIONSHIP BETWEEN INDUSTRIAL AND SYSTEMS SAFETY

An organized and systematic approach to safety may involve two or more separate but closely interrelated safety functions. First, there is the more traditional inplant industrial hygiene and safety function, which is usually oriented toward protecting the health and safety of each employee. This may be located within the Personnel department because it may be considered as a general overhead or burden charge (i.e., it is not financially chargeable to any one particular program or project).

A second type of activity would be the newer product-oriented System Safety function, which is concerned with the engineering design analysis and development engineering functions relating to the safe operational use of a particular product (e.g., an engine system). This type of activity, to be effective, is generally undertaken as part of the normal engineering design function. However, such a specialized function could easily become lost among the multitude of objectives, criteria, and tradeoffs seemingly heaped upon the shoulders of each designer and product review function (e.g., maintainability, producibility, value, operability, simplicity, schedule, checking, inspectability, quality assurance, reliability, and safety). To ensure that safety does not become just another vague design objective which could be inadvertently overlooked, there are increasing requests to designate or delegate some identifiable central responsibility to ensure that some organized and continuing effort is applied to meet the required operational system safety objectives. This might include, for example, provisions for independent design surveillance and audit of processes or functions relative to operational system safety.

INDUSTRIAL SAFETY FUNCTIONS

Industrial safety might include functions such as the following:

1. A Hazards Review Committee which could include the self-descriptive functions such as might be performed by a Flammable and Hazardous Chemical Committee, a Propellant Review Board, and an Exposure Evaluation Committee
2. A Safety Committeeman organization established at the workman level to report hazardous conditions or incidents
3. An Executive Safety Committee to establish safety policy. This could be a top-level management group consisting of the heads of each major company division and an executive at the level of vice-president. It is often felt that the prime responsibility for the day-by-day implementation of the safety program should rest with first-line supervision
4. An Industrial Hygiene and Safety organization could establish levels and criteria for operations involving use of hazardous materials; it might be, for example, concerned with the chemical and physical properties of new propellants and their possible toxicologic effects on propellant handlers. It could also review safety factors during the design and construction of test facilities, review written test operating procedures where potentially hazardous conditions exist, and conduct formal in-plant training courses dealing with Industrial Safety.

RELATION BETWEEN RELIABILITY AND SYSTEMS SAFETY

A review of the required, proposed, and suggested system safety engineering functions reveals a marked similarity to the parallel system development activities already required (and in existence) in engineering reliability organizations (Table 6). It is conceivable that many of the proposed system safety engineering functions could constitute part of another functional activity (i.e., reliability analysis), and that safety might be only one of several objectives of a functional activity (i.e., design review).

Such an approach to system safety would provide the greatest economy and efficiency of operation, while permitting flexibility to meet the varying demands of various missile/space systems programs. It would be essential that sufficient emphasis could be placed upon the system safety objective in each functional activity, and that some reasonable coordination of effort would be implemented.

SYSTEM SAFETY ENGINEERING

To achieve high safety standards, it is necessary to have a clearly organized, systematic approach to the problem of safety assurance. There are outlines* of the basic requirements to be met by Air Force ballistic

*AF BSD Exhibit 62-41, System Safety Engineering: General Specification for the Development of Air Force Ballistic Missile Systems, 5 October 1962; AF SSD Exhibit 62-161, Program 624A System Safety Engineering Requirements, 1 November 1962, and Proposed General Specification for Missile/Space System Safety, 30 September 1962.

TABLE 6

INTERRELATIONSHIP BETWEEN RELIABILITY AND SYSTEM SAFETY PROGRAM ELEMENTS

Reliability Function	Systems Safety Function
Identification of Human Error	Identification of Personnel Error
Design Review	Safety Design Review
Human Engineering Hazards and Safety	Design for Minimum Hazard Postanalysis Action
Failure Effect Analysis Malfunction Analysis	Catastrophic Analysis
Systems Analysis Personnel Subsystem Analysis	Safety Analysis Definition of Safety Characteristics Functional Flow Diagrams
System Test Acceptance Test Demonstration Exercise Category I, II, III Evaluation	Safety Test
Reliability Test Environmental Test Overstress Testing Simulation Studies	Special Safety Tests
Reliability Training and Motivation	Safety Training
Reliability Data Operation and Failure Reports	Safety Data Accident/Incident Reports
Reliability Analysis	Safety Research

NOTE: Other reliability functions may be involved in various types of safety analyses, i.e., packaging, maintainability, design services, standards, value engineering (depending upon the nature of the program and its mode of implementation).

missile systems contractors (in order to achieve an integrated and comprehensive system safety engineering effort). The intent of the application of safety engineering principles in system design is, according to these publications, to assure optimum freedom from inadvertent and destructive mishaps resulting from facilities, equipment, procedural, or personnel deficiencies either singly or in combination. It further states that the safety objectives should be "applicable to the design, research, manufacture, and test of the system or subsystem."

A review and analysis of various program requirements, state-of-the-art techniques in related activites, and current operational safety problems indicates that the elements of a system safety engineering program could involve the application of the following 10 procedures, methods, or techniques (in various combinations, depending upon the needs of a particular program):

1. Systems analysis
2. Safety motivation
3. Human engineering design surveillance
4. Personnel subsystem analysis
5. Systems test
6. Safety surveillance teams
7. Design review
8. Data surveillance
9. Catastrophic analysis
10. Human error investigation

Each of these activities are described in the context of the system safety program elements described in the following section of the report.

Where it would be desirable to have intensive coordination or specialization relative to system safety engineering, some central responsibility should be assigned for the coordination, implementation, and detail analysis of various work tasks (Table 7).

In general, an organized and planned system safety engineering function serves to emphasize safety factors during the early design and development of each system. Its approach is characterized by rigorous, step-by-step methods or controls to ensure that safety criteria cannot be inadvertently overlooked. The activity should cover all stages of product design, development, fabrication, inspection, test, maintenance, and use. The focus should be on the early identification and resolution of potential problems (i.e., on preventive action rather than corrective action following the occurrence of mishap).

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TABLE 7

ILLUSTRATIVE JOB DESCRIPTIONS IN SYSTEM SAFETY ENGINEERING

Job Title*	General Function	Typical Work Tasks
Hazards Consultant	Acts as technical expert who has specialized in system safety as a primary goal or field of specialization	Provide immediate state-of-the-art technical information, forecasts, and creative integration of applicable research data in the safety area Keeps up to date on various state and federal safety codes, technical committee recommendations, military and customer bulletins or specifications, and the latest technical literature in field Deals with safety as a primary professional emphasis Safety research coordination
Systems Safety Analyst	Performs detailed technical analyses and design studies relating to missile/space systems safety engineering	Performs detailed system safety studies, including functional and sequence analysis, to detect and correct sources of safety hazard in basic design and processing of system and supporting equipment Develops safety concepts Determines trends, desirable safety characteristics, and identifies safety hazards Works with others to determine parametric tradeoffs for system optimization or configuration studies
Safety Engineering Coordinator	Effects coordination between the various discrete events and analyses which occur in the design process and which involve systems safety	Integrates data obtained from various reliability program elements which relate to system safety objectives Focuses attention on safety design criteria

[illegible]	[illegible] coordination between [illegible] and analyses which [illegible]	[illegible] data obtained from various [illegible] reliability program elements which [illegible] safety objectives [illegible] attention on safety design criteria [illegible] application of safety analyses [illegible] and makes available all information [illegible] system safety to preclude decisions [illegible] upon lack of available or appropriate information
[illegible]	[illegible] the safety [illegible] and other groups [illegible] research, experiencing difficulties, or [illegible] activities related in some manner to system safety	Keeps in continuous contact, serves on boards or committees, coordinates, keeps informed, and deals with various industrial [illegible] fety, industrial hygiene, medical radiation, toxicology, hazards review, advanced [illegible] or research groups Ensures transmittal of safety data, evaluations, and current problems from various groups, locations, or activities Monitors various test and demonstration exercises relative to safety test objectives
[illegible] Design Engineer	Systematically reviews design drawings and maintains surveillance of procedures to ensure appropriate consideration of safety as a primary design criterion	Reviews proposals relative to potential safety problems Formulates a System Safety Engineering Plan (SSEP) defining the design-for-safety plan of action Performs systematic review of equipment modifications, facility layouts, installation, and maintenance data Provides a detailed review of procedures, checklists, and technical manuals to ensure appropriate safety precautions

*Some job tasks can be logically combined. For example, the hazards consultant and systems safety analyst tasks could be considered as analyst functions emphasizing human physiology. Similarly, the system safety liaison engineer and safety design engineer tasks could be considered as mechanical design functions emphasizing prior user experience and "design for safety" features.

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SECTION 6

SYSTEM SAFETY PROGRAM ELEMENTS

Specific system safety engineering methods, procedures, and illustrative techniques.

The preceding section dealt with the general approaches, background, and perspective involved in the safety engineering aspects of system design and development. This section of the report describes in detail some of the essential elements that are felt to be useful in the effective implementation of a system safety engineering program. Specific analytic techniques which could be employed are illustrated, and the relationship of these techniques to the matrix of related system development activities is presented.

SAFETY PROGRAM ELEMENTS

PART 1. IDENTIFICATION OF HUMAN ERROR

METHODS AND TECHNIQUES

The current need to reduce human error and the recent requirements for an organized program in this area were discussed in Section 5, Part 1 (Human Error and Goofproofing). In addition, 10 empirically derived principles encountered in human error analysis were described in Section 4, Part 5 (Human Error Principles). The following paragraphs desciibe the basic approaches or methods which can be used to identify sources of human error encountered during various phases of the system development cycle. The four principal methods are (1) systems analysis, (2) data surveillance, (3) simulation studies, and (4) direct observation.

SYSTEM ANALYSIS

The first approach, System Analysis, may involve any of the following techniques:

1. Detailed task analysis of the job operations required for operation, maintenance, transport, and assembly
2. Preparation of block diagrams representing each step in the functional flow or operations sequence
3. Review of conceptual and detail drawings, process specifications, and technical data to be used in support of job performance

These analyses serve to locate potential problems (based upon logic or theoretical assumptions, previous research, or past experience). They do not necessarily require the presence of physical hardware. Hence, they may be performed sufficiently early in the design cycle so that changes can be effected before design or procedural concepts become too fixed. Incidentally, the information derived from these analyses is of decided benefit to a number of other functions in the system development cycle.

DATA SURVEILLANCE

The second approach, Data Surveillance, may involve any of the following:

1. Monitoring the failure reporting system to locate specific cases of human-initiated failure
2. Reviewing test malfunction or incident reports, field operation reports, or component laboratory reports for incidents which might involve human error
3. Sampling the inspection discrepancy, quality history, part replacement requests, maintenance forms, or equipment logs

Data Surveillance is an indirect means for locating probable instances of human error. However, sufficient background information for properly interpreting the failure, malfunction, incident, or difficulty may not always be present. The failure may be described in terms of symptoms or results, not in terms of cause or contributing factors. How many individuals would willingly accept the consequences of reporting "I dropped and damaged the part," rather than state that the part was received in a damaged condition? The question is whether there is a high enough proportion of minor or quick replacement items reported in a data reporting or log system. Looking at the problems involved in data surveillance, it can be said that this is an excellent means for locating problems if the incidents are treated only as leads for further direct investigation.

SIMULATION STUDIES

The third approach, Simulation Studies, may involve the use of a close physical model or approximation of the equipment, process, or subsystem under study such as:

1. Cardboard mockups, soft mockups, battleship mockups, R&D hardware, or prototype equipment for early or initial studies of human performance
2. Special research apparatus for static or dynamic simulation of unique man-machine problems
3. Production hardware in a simulated operational situation for various verification, validation, demonstration, acceptance, or Category I test exercises

Simulation studies provide data on observed instances of human error or difficulty. While simulation studies are somewhat artificial because they only approximate the real situation, they do provide human error data not usually obtained solely from systems analysis studies (which are only predictive in nature), or from data surveillance studies (which must sample an information flow which is easily biased, restricted, or screened). Simulation studies do provide a systematic and intensive means of gathering data concerning human performance factors.

DIRECT OBSERVATION

The fourth approach, Direct Observation, involves systematic and thorough personal observation of all scheduled and unscheduled job operations on existing equipment configurations in the operational or working situation. It could include personal observation during any of the following:

1. Transport, receive and inspect, storage, assembly, installation, checkout, or test operations
2. Attainment of initial operational capability, operational training exercises, special operational R&D projects, or even in a special operational systems test facility as an integral part of a Category II test program
3. Normal operation of the system either as part of a Category III test program or to ensure that the inherent reliability of the hardware or process is not inadvertently or unknowingly depreciated.

Direct observation is often disparaged because it is assumed that (1) the observation is post facto, (2) the hardware is frozen, (3) procedures are already established, and (4) any change would be very costly. However, often it is not as late in the system development cycle as one might believe, and such direct contact often is very necessary to achieve the full inherent operational effectiveness of a system. It may also be of importance in terms of modernizing, updating, or modifying downstream equipment. It is certainly an effective means for systematically accumulating and evaluating "real-life" data that can be applied to related systems then in the planning or design stage.

The very process of conducting systematic direct observation on fairly large, complex systems in the operational environment has often been termed impossible or unscientific (because of the lack of experimental controls) by individuals most familiar with laboratory or behavioral research. However, even informal, short-term, direct observation of a small segment of a working situation generally yields some practical and useful information about "real-life" problems.

During the past few years, the technique for conducting field research on large-scale man-machine systems has evolved or been developed. This technique is based upon empirical data such as the recorded observed difficulties or deviations from a prescribed template of required human performance by all personnel involved in the system. It is a broadly oriented means for identifying even the cumulative minor problems which people actually face in attempting to operate and maintain a system composed of a conglomeration of various items of equipment, personnel, procedures, and support functions. The problems which serve to induce or foster human error may relate to (1) equipment design interfaces, (2) organizational control procedures, (3) technical data such as checklists used to guide human performance, (4) previous personnel training or the maintenance of skill proficiency, (5) availability of tools or test equipment, and (6) alteration or nonavailability of appropriate procedures.

PART 2. SYSTEMS ANALYSIS

To apply safety engineering principles to all aspects of product development, some early and orderly means must be employed for identifying and subdividing all functions where hazardous personnel-equipment interactions might occur.

DIAGRAMMATIC REPRESENTATION

One technique (which is an aid in performing a systems safety analysis) involves the sequential identification and description of all functions, phases, events, processes, or elements of the system under consideration. Block diagrams representing groups of systems elements may be prepared. These block diagrams result in conceptual building blocks that enable further schematic representation of the functional flow and system element interrelationships. Further detailed information regarding each system element can then be prepared in the form of task analysis work sheets, narrative functional analyses, or other detailed systems analysis forms. The interrelationships and derivative data are obtainable by transposing these data to tabular, data pickoff, and matrix charts. These charts are found in position equipment task summaries, integrated task inventories, equipment-maintenance analyses, equipment function matrixes, personnel data cards, maintenance loading charts, etc.

These block diagrams may be prepared as an aid during the systems analysis of any one of a wide variety of activities. It may be of use in these ways:

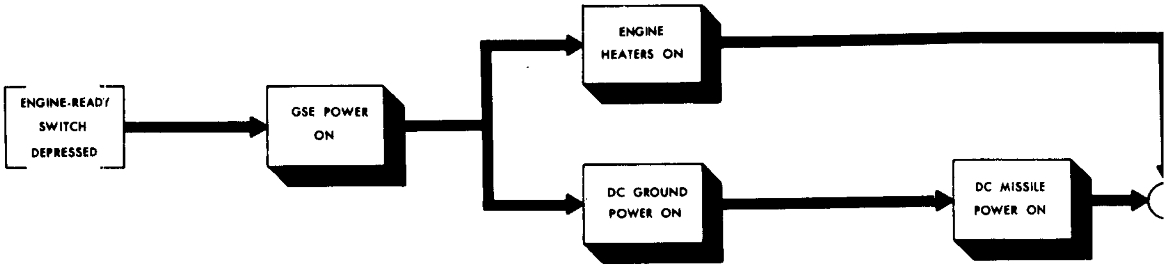
1. Locating inadequacies in the control of the routing of parts during manufacturing operations
2. Detailing assembly operations to determine the nature of required technical data support
3. Determining manning or tool requirements for items of ground support equipment
4. Determining areas of safety hazard in the operational employment of the system

This tool or technique then is fairly flexible, as indicated in the Sequence Charts (Fig. 5) and the applications given below.

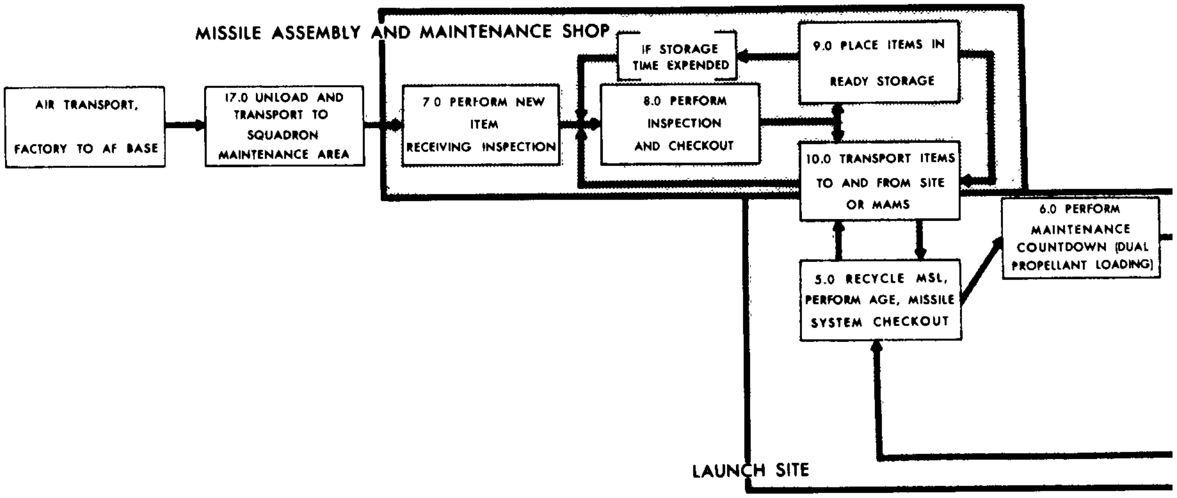
It is important to recognize that the information contained and method of pictorial representation selected for diagramming should vary as to the purpose and subsequent use of the analysis. The block diagram is only a tool in an evaluation or descriptive process. In general, block diagrams will contain block descriptors and codes, predecessor and event dependencies, recognizable milestones or locators, dummy or redundant blocks, and significant interface event/activities (Fig. 4). The consistency and rigor of this standardized or forced-think approach is one of the essential properties and chief values of the technique when it is utilized for evaluative purposes.

A somewhat analogous approach to systems analysis may be found in various time, motion, or industrial engineering studies. For example, information on product process, form process, man process, therblig, simo, multiactivity,

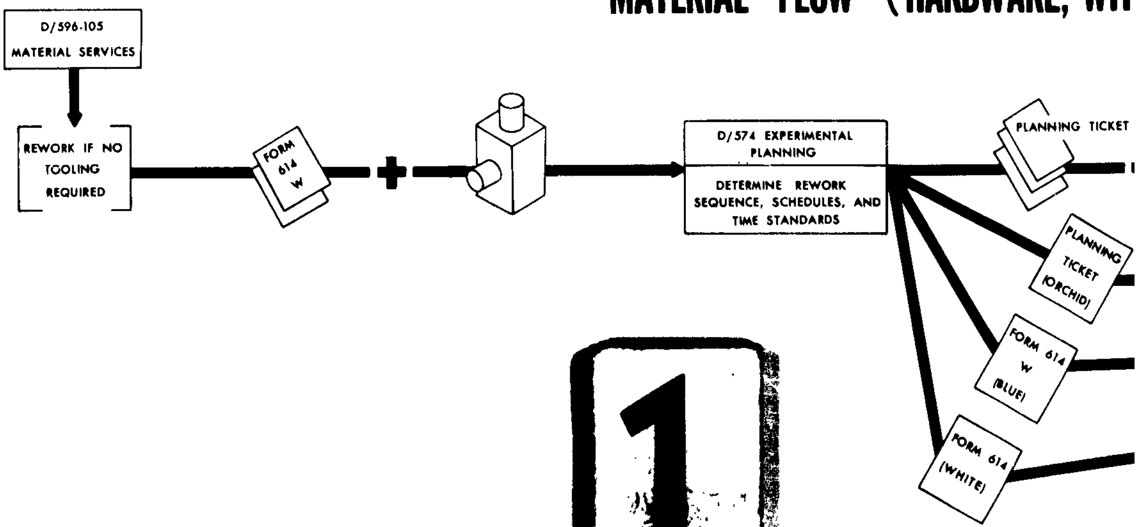
SEQUENCE OF EVENTS (DISPL



FUNCTIONAL FLOW (JOB OPERATIONS, V



MATERIAL FLOW (HARDWARE, WIT



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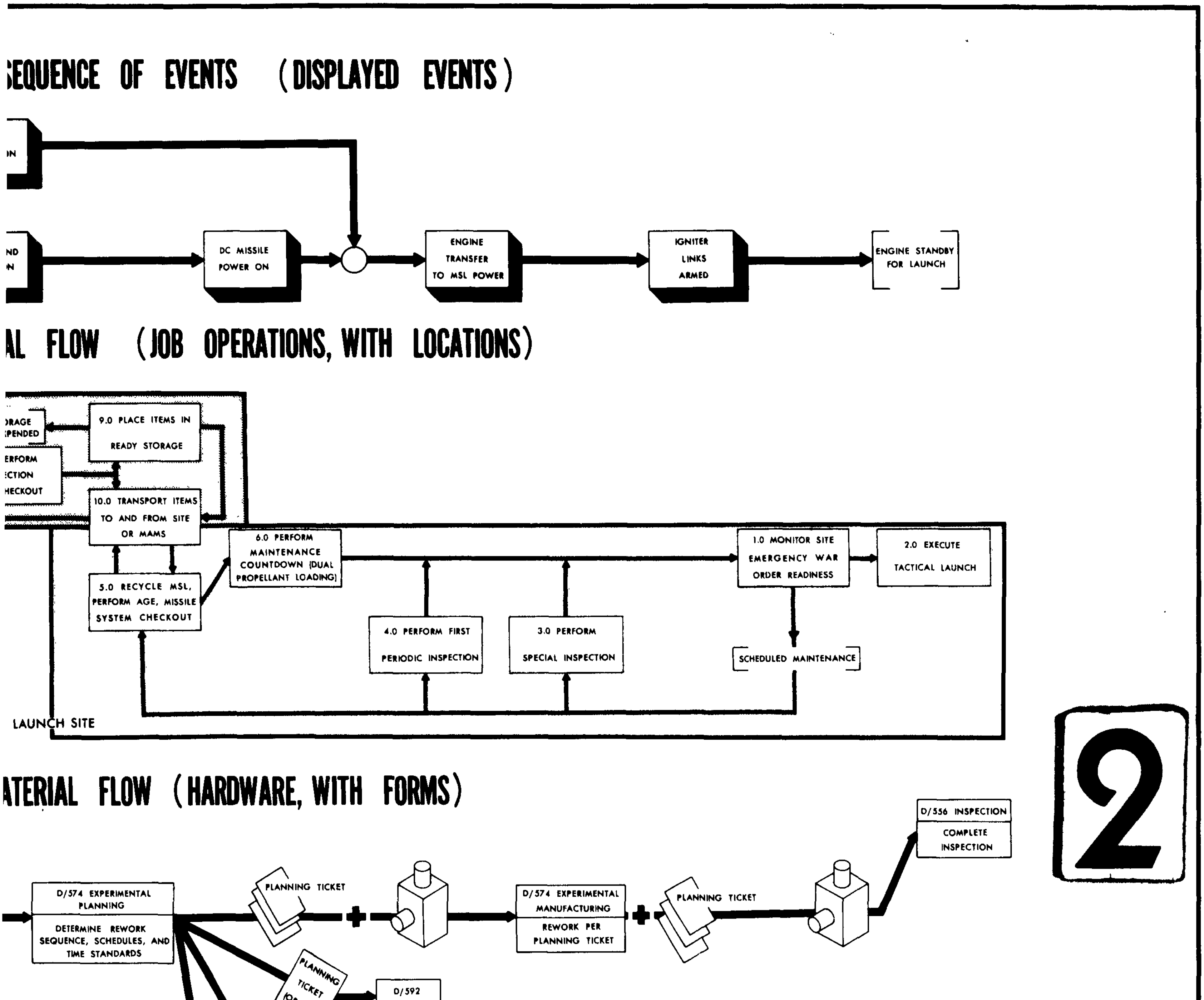

Figure 4. Systems Flow Chart

CLASSIFICATION	DIAGRAMMATIC EMPHASIS	EXAMPLES
SEQUENCE OF EVENTS (OCCURRENCE OF DISCRETE SYSTEM EVENTS)	INTRINSIC EVENTS (HIDDEN)	OPENING AND CLOSING OF VALVES; MAKING AND BREAKING OF RELAY CONTACTS; ETC.
	DISPLAYED EVENTS (TRANSDUCED)	LEGEND OR INDICATOR LIGHTS; PANEL SCHEMATICS; CRT DISPLAY; ETC.
	OBSERVED EVENTS (OVERT)	DIRECTLY OBSERVED MECHANICAL ACTUATION; MISSILE ERECTED; LIFTOFF; ETC.
FUNCTIONAL FLOW (DISCERNIBLE STEPS)	JOB OPERATIONS OR WORK TASKS (WHAT)	PERIODIC INSPECTION TASKS; ASSEMBLY OF TURBOPUMPS; ETC.
	GEOGRAPHIC LOCATIONS OR WORK STATIONS (WHERE)	FINAL ASSEMBLY LINE; ELECTRICAL HARNESS BUILDUP; ETC.
	WORK SCHEDULE OR TIME LINE (HOW LONG)	OPERATOR TIME LINE CHARTS; OPERATIONAL ANALYSIS; ETC.
	INPUT-OUTPUT ANALOG (INTERACTION)	INFORMATION HANDLING NETWORK OR TRANSFER DIAGRAM
MATERIAL FLOW (PHYSICAL MOVEMENT)	DATA FLOW (PAPER)	FORMS; TECHNICAL DATA; COMMUNICATIONS; REPORTS; ETC.
	HARDWARE PROCESS (PARTS)	MOVEMENT OF COMPONENT DURING FABRICATION; TRANSPORT OF MISSILE; PARTS SUPPLY; ETC.
PLANNING AND CONTROL (ANTICIPATED ACCOMPLISHMENTS)	PROGRAM SCHEDULE (MILESTONES)	PROGRAM MILESTONES; PERT; SCANS; DATA SUBMITTAL POINTS; PROJECT ELEMENTS; DEVELOPMENTAL STEPS; ETC.

Figure 5. Sequence Charts

and operation process charts, symbols, and diagrams may be found in various texts.* The differences which exist between the human factors and the industrial engineering approach reflect the differences in orientation, perspective, purpose, and use of the techniques involved.

Reliability functional block diagrams may be used during quantitative reliability allocation and estimation or for a graphic presentation of total system capability. The use of reliability functional block diagrams to identify model elements against which to apply operating time and cycle data may be found in the Atlas OSTF Reliability Mathematical Model Program. In this case, it was possible to utilize standard tactical operational conditions (STOC), i.e., standby, countdown, flight, first periodic maintenance, etc., for the basic building blocks of the model.**

Such logical functional blocks in a systems operational diagram can be assigned probability values and distribution functions of a predicted or an empirically derived nature. Various combinations of the functional blocks can then be utilized to determine a total or composite reliability estimate for a given sequence of operational functions. For example, a set of six functional blocks may represent the six job operations required to launch a particular missile. If reliability estimates are available for each of these job operations, based upon the set of events or tasks involved in each job operation, a total reliability estimate

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*e.g., Nadler, G.: Motion and Time Study, McGraw-Hill Co., New York, 1955, 65-187.

**See Lough, T. M. and E. Cupo: Proposed Reliability Measurement Method for Atlas E and F Weapon Systems, Reliability Mathematical Models-General Description, 6301-6214-RU000 (Preliminary), Space Technology Laboratories, Inc., Inglewood, California, 3 May 1962.

could be calculated for this launch sequence based upon a particular weapon system configuration. One recent detailed study, utilizing data gathered specifically for this purpose and applied to a model representing the operational situation, may be found in a Rocketdyne report.* Supplemental remarks on the relationship of such models to human performance research may be found in Part 6 of this report under Operational Systems Test (page 259).

TASK ELABORATION

Following completion of the initial draft of a systems functional flow chart (e.g., those for user-scheduled job operations), the stage of analysis best described as a task elaboration may be started. Each block of each functional flow chart may be treated as a discrete task and can be methodically analyzed for the man-machine interface factors which must be resolved or supported by job instructions, training, training equipment, safety equipment, equipment design features, special tools or test equipment, etc. This task elaboration develops what is commonly referred to as a Personnel-Equipment Data (PED) pool or Personnel Subsystem Basic Data Pool. (See Section 1 of HIAPSD, AFSCM 80-3, July 1962 edition).

Some of the first generation of paperwork produced are typified by the Preliminary Task Index, Time-Line Task Analysis, Qualitative and Quantitative Personnel Requirements Information (QQPRI), Training Concepts (TC),

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*Karkau, A.: OSTF-1 Reliability Mathematical Model Program, Final Report, Rocketdyne Report R-3925, 15 December 1962.

Technical Manual Planning Documents, Position-Equipment Task Summary (PETS), and various preliminary maintainability and reliability planning documents. The relationships of these documents to each other and to subsequent generations within the PED or PSS basic data pool may be seen in Fig. 7 (Section 6, Part 5, Personnel Subsystem Development Cycle (page 251)

Perhaps the core documents generated during the task elaboration stage of analysis are the Task Analysis Worksheets (TAWS), which contain both detailed task descriptions and training information. AFBM58-7, Exhibit for Development and Preparation of Task Analysis Data for WS 107A-1 (1 October 1958), presents some of the early thinking concerning what TAWS should contain. (See also AFBM Exhibit 60-65A, Aerospace System Personnel Subsystem Development, 17 November 1961.) Many companies that have prepared TAWS according to this specification have found additional significant information which has needed to be delineated. Such specifications should therefore be considered as simply a valuable aid or guide in getting started in the right direction.

One of Rocketdyne's recent TAWS had a format which was 10 pages long; 6 pages detailed such information as task name, location, frequency, starting cues, completion cues, detail steps, assumptions, tools and test equipment, materials, technical data, quantities and types of personnel, environmental conditions, requirements for speed, communications, special skills, etc. Some items of particular interest to a system safety engineering effort are:

1. An evaluation of task criticality
2. An estimation of the probability of human error
3. An analysis of requirements for special care or special handling of equipment

4. A delineation of sources of special danger

5. A rough indication of procedural or equipment means for minimizing or controlling these hazards.

Additional items might include predictions of probable and potential equipment damage, contamination, and/or personnel injury. The final four pages of the Rocketdyne TAWS contained such training information as:

1. Type of information transmission desired (i.e., simple or detailed circuit knowledge, component location, construction, operation, etc.)

2. Anticipated training difficulties

3. Assumptions concerning prior training, skills to be learned, class descriptions, method of evaluation of learning, training time, visual aids, training equipment, malfunction insertion capabilities, etc.

One item, Student Safety Precautions in Performance of Task, presented an opportunity to incorporate into both the student's classroom and integrated training the safety skills, knowledge, and attitudes identified as necessary in the previous pages.

If the TAWS are prepared at the proper stage of system development, they could become a basic source of information for many purposes, including preparation of maintenance handbooks, checklists, inspection work cards, some types of process specifications, training plans, personnel performance checklists, portions of parts and materials provisioning schedules, etc.

Task analysis material (i.e., PED) may also be used in the preparation of Unit Proficiency Exercises designed to evaluate the operational readiness of missile crews. Such exercises* may employ a three-point rating scale on each of these factors: (1) procedures, (2) time, (3) equipment handling, (4) communications, and (5) personnel safety. This resulted in a seven-point final rating for each exercise. Such a procedure would permit the isolation and comparative group rating on a personnel safety/proficiency test objective.

One limitation of this evaluation approach is that it requires the use of at least one highly proficient and knowledgeable team to observe, rate, and evaluate the performances of other crews. This is the Strategic Air Command, UPS Standboard Team concept. Evaluations by training instructors, development engineers, or other persons who are not actually direct working personnel may result in only superficial validity and could result in biasing from the personal eccentricities or preferences of the evaluators. This tendency is not completely absent using the standboard team approach, and it could be controlled to a greater degree if several evaluation teams were cross checked by a standardization team.

APPLICATION TO HUMAN PERFORMANCE EVALUATION

An evaluation of human performance during systems testing is predicated upon the gathering of a body of appropriate and significant test data. But, what sort of man-machine interaction data should be gathered and

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*e.g., R-2771, Unit Proficiency Exercise Instructions for MA-2 Propulsion System Troubleshooting (Experimental), Part II, Rocketdyne, A Division of North American Aviation Inc., Canoga Park, California 23 February 1961.

reported? What consitutes a reportable incident? Is there a consistent standard that can be used to gather objective test data in situations that may be fairly complex in terms of the work or activities to be observed? There is a reliable and valid standard that can be used; it involves a vital concept in system testing, the nature and significance of which will be concisely described.

In experimental laboratory research, all extraneous variables are rigidly controlled while the independent variables are manipulated in a carefully defined fashion. The data obtained are in terms of objective measurements of the dependent variable. The correlation or relationship between the manipulated and dependent variables can then be determined (Fig. 6).

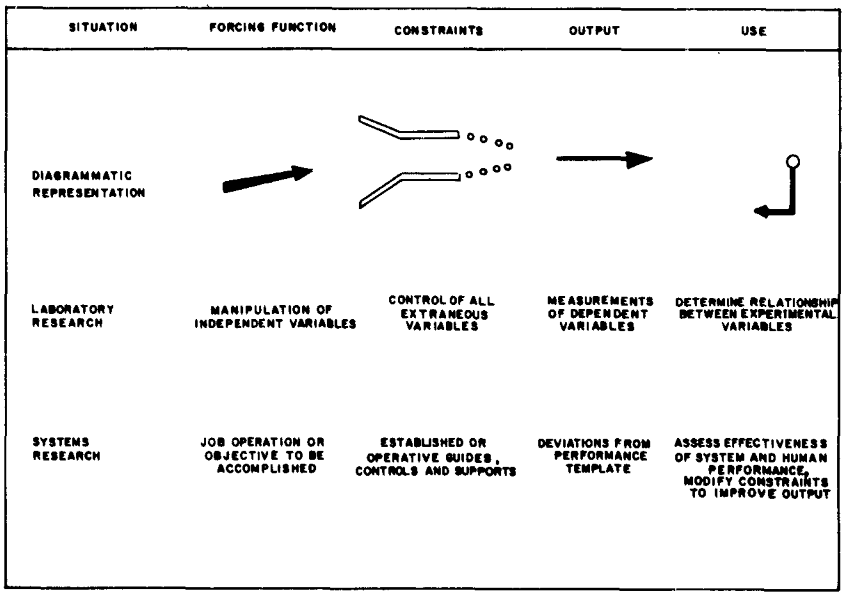


Figure 6 . Test and Evaluation Parameters

In system testing, there are also constraints, limits, or restrictions as to what should occur during the test activity. These situation constraints are established by virtue of the procedures and tasks specified in (1) performance guides (i.e., job manuals or operation and maintenance checklists), (2) organizational controls employed, (3) prior training of the crew, (4) equipment used, and (5) physical facilities involved. The forcing function, which may be invariant, is the particular job operation or test objective to be accomplished. The only meaningful measurements or data which can be obtained are the deviations from the expected or prescribed pattern of activity that could result in changes (variance) in the desired or specified system performance.

One essential difference between experimental and system research is that system testing involves determinations of the relationship between output and the constraints, rather than between the independent and dependent variables. That is, if the output is not adequate and significant deviations are found, the remedy involves altering (i.e., improving) the constraints which serve to guide or control human performance. It is assumed that every deviation has one or more causes for which remedies can be instituted. The successive elimination or control of causes, by changing the constraints, will both upgrade product reliability or systems effectiveness and provide additional reliability assurance control.

The detailed information which can be obtained from a system analysis and task elaboration is of particular importance for systems testing because it provides, in conjunction with other documents, the information necessary to establish the standard or template of required human performance. This standard should be clearly established and defined by translation into a personnel performance checklist (to be used during the actual observation of task performance).

The review of systems and task analysis information also provides the observer with background information as to probable errors and their criticality, the required crew training, safety precautions, special skills, etc. Therefore, the systems analysis activity is a vital prerequisite for a maximally productive observer and analyst function in a system test program (See Section 6, Part 6, System Test (page 257); Section 1, Part 2, Method or Approach (page 7); and Section 4, Part 4, Generality of the Findings (page 187).)

PART 3. SAFETY MOTIVATION

OBJECTIVES

To attain ultrahigh safety goals, it is necessary to provide some means for the safety orientation, indoctrination, and motivation of individuals in various departments or facilities who may be involved in critical aspects of system development. This is important to forestall or reduce those sources of personnel error, carelessness, oversight, or indifference which may be due to lack of knowledge of the safety and reliability goals, and the effect of each individual's actions on product effectiveness. The general objective of this effort is to effectively focus the capabilities or talents of various specialized groups toward achieving a vigorous safety motivation effort. This, in turn will (1) heighten employee motivation, (2) assure appropriate and positive attitudes toward safety objectives, (3) improve the transfer of critical job skills, and (4) increase work proficiency to meet higher safety and reliability standards.

SAFETY ORIENTATION AND INDOCTRINATION

Initial safety orientation is needed for employees who are new to a program (to emphasize the unique needs and special requirements of that program). Continued safety indoctrination of a limited nature may be desirable to emphasize program objectives, procedures, problems, and accomplishments.

The initial safety orientation may utilize general safety and reliability films, printed material, lectures, discussions, audiovisual training aids etc., as needed.

The continued safety indoctrination may be accomplished by means of films, newsletters, closed circuit television, conferences, posters, etc., as deemed necessary and appropriate in terms of cost.

SAFETY MOTIVATION

Motivational training aids or devices may be employed to secure changes in attitude or motivation relative to specific safety problem areas or technical objectives.

The use of special techniques, such as audiovisual devices, could be employed in certain critical areas. This should be done on a limited basis following careful study of the actual need and optimum programming techniques which should be employed. It is important that there should be thorough coordination between various groups which could contribute to an understanding of the problems involved in attempting to secure attitudinal change. Reviews of proposed motivational training aids or programs should be made by a qualified psychologist, industrial psychiatrist, or human factors engineer.

SAFETY TRAINING

Special intensive training may be deemed necessary to improve the transfer of critical job skills or to develop new skills for improved procedures and operations. Significant detailed safety information must be communicated on a timely basis to foster greater utilization of experience-retention services and encourage the use of safety techniques and services.

Safety training may be implemented by special training courses, lectures, conferences, research reports, and specialized audiovisual programs (Table 8). In some cases, it may be beneficial if human factors personnel assisted in the preparation of specific training course materials.

TABLE 8

SAFETY TRAINING PROGRAM

Type of Training	When Administered	Emphasis on Content	Aims or Objectives	Illustrative Mode of Implementation
Orientation	Initially	Basic introductory information	Alert, develop interest, promote understanding	General films, lectures, brochures
Indoctrination	Continually	General or topical information	Maintain awareness of reliability and safety goals	Newsletters, posters, pamphlets, safety design tips, promotional devices, displays
Training	When needed	Detailed job knowledge	Skill transfer or improvement	Training courses, special films, safety research reports, handbooks
Motivation	As required	Specific problem areas	Attitude formation or change	Conferences, team efforts, audio-visual programs, small group discussions

PART 4. HUMAN ENGINEERING SURVEILLANCE

GENERAL OBJECTIVES

The design of all man-machine interfaces should be in accordance with generally accepted human engineering design principles and practices. These design criteria provide for maximum simplicity and ease of handling, servicing, and operation. A careful assessment should also be made, during design and development, to determine the relative biomedical health hazards and possible equipment dangers to operating, handling, and maintenance personnel. Potential personnel hazards should be reduced or eliminated through the use of design features which minimize the possibility of accidental injury. An attempt should be made to ensure that the design prevents, or is maximally resistant,to the sources of human error anticipated in the operational environment. An attempt should be made to minimize and simplify the maintenance, storage, and handling procedures. Careful attention should be paid to the procedures for the diagnosing, confirmation, and correction of malfunctions.

Consideration should be given to those interface areas of design (both contraction items and those of other contractors) which have implications in regard to personnel skill, training requirements, job aids and manuals, and test and evaluation procedures. The primary objective would be to provide specialized human engineering technical information, analyses, and consultation services to various design and development groups and design review boards, as well as review or study requirements of the customer or user.

IMPLEMENTATION

A relatively formal design review activity should routinely consider the human engineering aspects of equipment design during its Preliminary, Critical, and Production Release reviews. A specialized human factors review procedure should also be available throughout the development of preliminary design specifications, establishment of detail design, construction of mockups and prototype equipment, and the field testing of operational equipment. Formal checklists containing human factors safety criteria should form part of the prereview design review procedure. (See the Data Evaluation section for further information on safety checklists.) The design review function is extremely important in order to preclude inadvertent omission of relevant human factors considerations early in the design process.

Specialized detail technical information and analytic studies relative to human factors engineering should be provided, on a timely basis, to various engineering design and support groups during the development of the system.

Emphasis should be placed on the system integration (relative to human factors) of the engine system and its associated equipment in assembly, test facilities, and in the vehicle. The implications relative to training requirements and training equipment (manuals of operating and maintenance instruction manuals) and the evaluation of on-the-job skill or proficiency factors should be carefully considered. In addition to the design review function, it is necessary to participate in various three-dimension real-life hardware tests and evaluations. Finally,a series of human engineering evaluations should be conducted to verify the adequacy of human task performance, safety, and human reaction to the system, relative to the operational system in the operational configuration and working environment.

CRITERIA

Human factors engineering may involve research, analyses, tradeoffs, and assessments (performed by qualified human factors engineers, perceived in terms of the intellectual and physical capabilities of the intended user, and with appropriate consideration of the personnel-logistic-physical-social environment actually experienced during use of similar equipment). These assessments involve consideration of the following factors:

1. Displays, controls, and display-control relationships
2. Panel and work space layout
3. Physiological requirements; including health hazards and personnel comfort (where it may significantly affect efficiency or effectiveness of required human performance)
4. Safety during operation, maintenance, transport, or other work tasks
5. Ease of operation and simplification of maintenance tasks
6. Environmental factors; such as temperature, humidity, dust, fumes, noise, vibration, blast, lighting, etc.
7. Communications required during various job operations
8. Procedures; including technical data support documents
9. Human dimensional and dynamic characteristics
10. Visual and auditory factors as they affect human performance
11. Training and training equipment, work skills, evaluation and maintenance of job proficiency

ALLOCATION OF HUMAN ENGINEERING EFFORT

It is vitally important to properly phase, time, and allocate the required human engineering effort in accordance with the expected system development stages and typical design process. Without appropriate advance planning, opportunities to perform human engineering evaluations will not become immediately obvious. Such evaluations are most economically performed in conjunction with other tests, review procedures, or evaluations (and these easily overlooked opportunities rarely recur). Table 9 serves as an aid or guide in planning the timely, systematic, and rigorous incorporation of human engineering effort in a program plan or plan of action. Obviously, the extent of such an effort would vary from a sampling in areas of maximum likelihood of beneficial results, to an exhaustive reliability assurance effort. The extent of effort would be affected by budgetary restrictions, the unique needs of a particular program, available talent, the existence of various facilitating or limiting factors in the developmental process, the qualifications of applicable governing specifications and requirements, and the constraints of the existing state of the art.

TABLE 9

HUMAN ENGINEERING MILESTONES

Stage	Reliability Milestone*	Human Engineering Function	Human Reliability Estimate**
1	Detailed design study	System analysis	Predicted
2	Preprototype	Static mockup, model, drawing, and simulation studies	Interpolated
3	Prototype	Dynamic simulation and procedures development	Empirically derived
4	Production demonstration	Verification and validation	Refined
5	Demonstration of service readiness	Category I, personnel subsystem test and evaluation	Demonstrated
6	Service evaluation	Category II and III, personnel subsystem test and evaluation	Achieved
7	Full-scale production	Monitor process, product, and system application and use	Surveillance
8	Demonstration of major product improvement	Modification and special system test and evaluation	Validation or revalidation

*These general reliability milestones are specified in Air Force Regulation 375-5, Reliability Program for Weapon, Support, and Command and Control Systems, 17 October 1960

**Quantitative or quasiquantitative human performance mathematical model, operation, or maintenance tradeoff, task time, or personnel subsystem data estimation

PART 5. PERSONNEL SUBSYSTEM ANALYSIS

GENERAL OBJECTIVES

The Personnel Subsystem (PSS) is a systems analysis and data development program to ensure the adequate consideration of all factors affecting personnel performance. One basic objective is to provide for the detailed information which is required to ensure delivery of qualified personnel and valid support documents concurrently with delivery of hardware to the using agency. It provides for the derivation of personnel-equipment or task analysis data to be used for:

1. Development of technical manuals and checklists
2. Identification of training and training equipment requirements
3. Maintenance support information
4. Human engineering evaluation of task performance and equipment design
5. Requirements of a system test and evaluation program

(The methods used to derive such data were described in Part 2, Systems Analysis (page 225).)

DIFFICULTIES AND CONTEXT

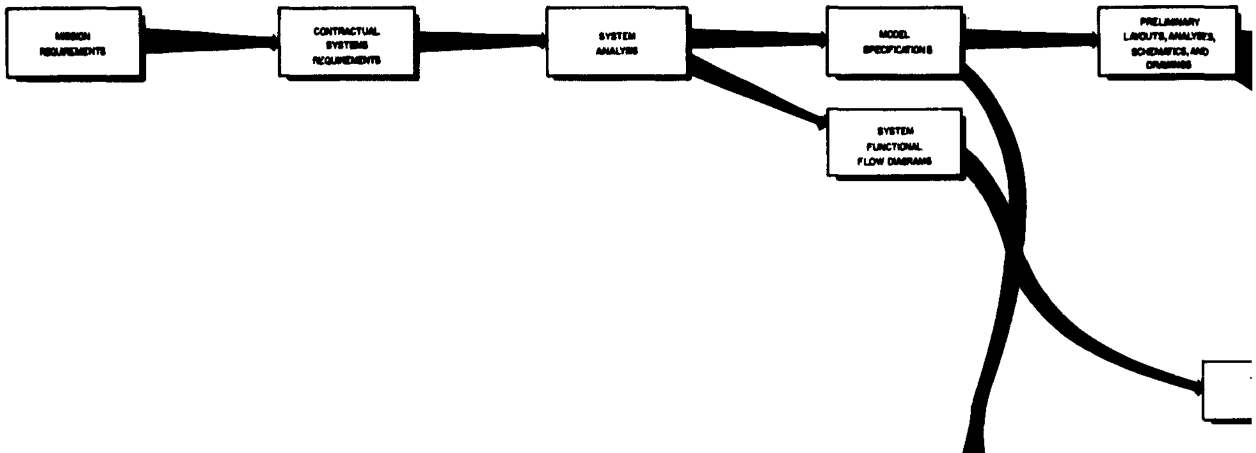
In the past, the primary emphasis in Personnel Subsystem activities has been on basic data development below the level of the systems analysis function. Such development would include:

1. Systems Functional Flow Diagrams

2. Quantitative and Qualitative Personnel Requirements Information (QQPRI)
3. Task Index with time line
4. Position-Equipment Task Summary (PETS)
5. Training requirements
6. Training equipment justification
7. Technical Manual requirements
8. Basic field requirements for collection and validation of PSS data

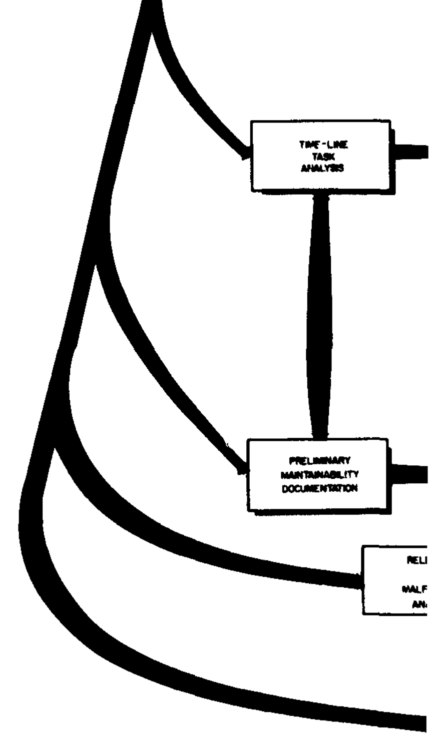
Therefore, the identification of safety hazards and the description of personnel protective materials and procedures was in terms of what would be required during training or customer use of the system under study. The actual effect upon project-oriented engineering design and development activities has not been as great as it could have been if (1) system analysis had been initiated earlier in the development cycle, (2) PSS analysis activity had been performed in closer association with the design and development groups, or (3) PSS activity had better defined and more effective points of contact, such as a project-oriented safety function through which to effect desirable (safety) changes in design or procedure.

Probably the major difficulty in the implementation of a maximally effective personnel subsystem program is the very breadth and complexity of the process involved--plus the interaction and interdependency with other organizational functions. This is perhaps best illustrated by the matrix of activities shown in Fig. 7 . This figure represents somewhat of a



Notes:

1. Not all interactions are shown. Substantial cross fertilization between human subsystem elements is implied (e.g., maintenance and task information should heavily influence the formal equipment layout and design review process).
2. Time sequencing shown may vary to accord with the exact nature of the development project and various organizational responsibilities (e.g., Preliminary Operating and Servicing Instructions may be derived directly from Process Specifications or TAWS, maintenance data may be combined with task analysis or PED, and TOTM elements may involve many discrete steps).
3. Each block may be expanded into a separate flow chart to show what should or did occur, its preliminary or followon phases, and its supplemental input-output or interaction relationships.
4. In the interests of simplicity, certain vital human subsystem functions are not shown (e.g., test and evaluation, human engineering, and systems management) because of their general and repeated application at various stages of the development cycle.



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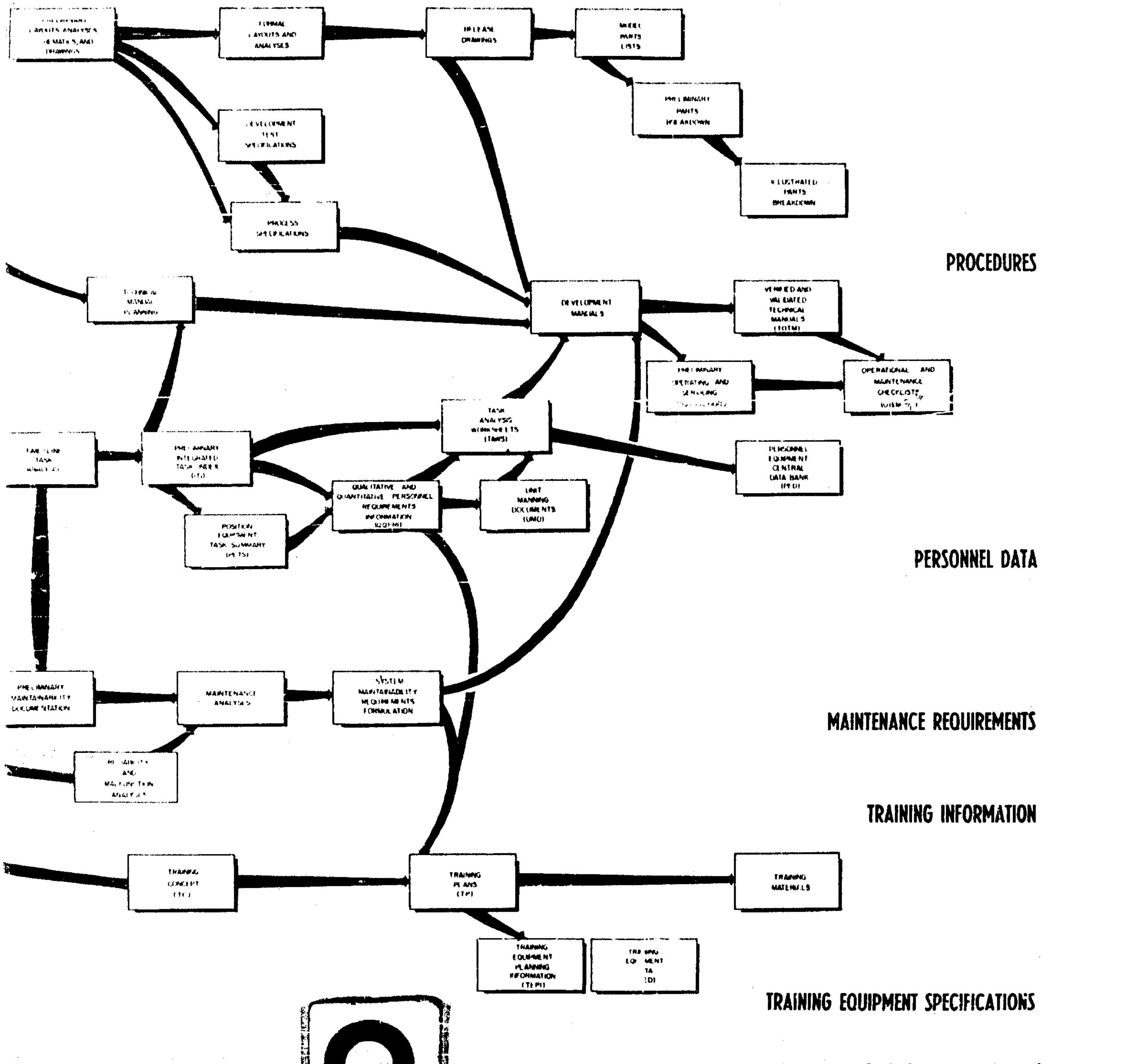

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Figure 7. Personnel Subsystem Development Cycle (Documentation Milestones: Time-Sequenced Elements in the Development of Basic Human Performance Information)

compromise position between the various desired, ideal, and theoretical positions held by specialists in this field and the constraints, realities, and forcing functions found to affect such a program. The rapidly developing state of the art and current material in the field is reflected in the expanding content of Handbook of Instructions for Aerospace Subsystems Designers (AFSCM 80-3; see also Appendix F, Related References).

IMPLICATIONS FOR FURTHER RESEARCH

Only a few of the missile and space system development programs have had a requirement for a formally organized Personnel Subsystem Program. In some cases, similar functions may have been performed by various discrete organizational elements under a variety of descriptive headings. In other cases, little may have been accomplished in terms of what some specialists in this area may feel is appropriate or necessary. This may be indicative of the wide differences of opinion that exist relative to the following questions regarding the general applicability, the time and place of accomplishment, the methods employed, and the costs involved in a personnel subsystem program:

1. General applicability. Most system engineers seem to agree that PSS is a necessity for the more complex systems. However, is such an involved effort really necessary for smaller programs or systems which will not involve a great deal of operation and maintenance activity?

2. Time and place of accomplishment. Is such an effort best accomplished by the participation of all subcontractors working on the development of a system, by just a few selected associate contractors, or by the selection of one prime, integrating, or separate systems contractors for just this purpose? Is it predominantly a product support, technical data, or systems engineering function? At what stage of system design could PSS analysis most effectively and economically take place? Should this be based upon the extent to which PSS problems might affect equipment design or the need for constantly updated product support information?

3. Methods employed. Does the method of implementation (of the PSS basic data program) actually facilitate the designer's task, or does it tend to impose additional burdens by requiring him to supply or continuously review various types of information? Do the resultant documents and data find ready acceptance and serve to facilitate the accomplishment of all of the various functions which could profitably use such information? (These questions indicate the need for much more direct research on the integration of PSS activities within the system development cycle to obtain greater acceptance and more profitable use of derivative information.)

4. Costs involved. Where funds are very limited (as they usually are), is there a more economical, efficient, and timely means for basically accomplishing the same goals? Is this the best means of utilizing available talent for the purposes intended? Could surges of manpower be avoided in producing initial and periodically updated documents? Would simplified forms and more discrete or narrower goals violate the multipurpose utility of a central personnel-equipment data bank?

While such questions may be thought provoking,* it must be remembered that the very concept of a personnel subsystem program would not have been formulated or found acceptance had there not been a recognized need or some known better means to fill that need. These questions should not be interpreted as a challenge to PSS concerning its basic right to exist. They serve only to indicate that the requirements for personnel subsystem programs should be flexible and modifiable in terms of the unique requirements of various system development programs. Also, they should have provisions for the incorporation of continued advances in the state of the art of this type of endeavor. It also indicates that further research on hypotheses derived from these questions should result in personnel subsystem procedures which would be of even more benefit in the system development and operational employment cycle.

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*See Majesty, M.S.: Research Proposals for Personnel Subsystem State-of-the-Art Advancement in Ballistic and Space System Development, DCAS-TDR-62-80, Ballistic Systems Division, Air Force Systems Command, Inglewood, California, 22 March 1961.

PSS SAFETY DATA

It is obvious from Fig. 7 that system safety is an integral and vital part of the personnel subsystem. The PSS activity will produce data related to the following system safety objectives:

1. General missile system safety requirements
2. Identification of potential safety problems
3. Determination of support equipment relative to safety considerations
4. Delineation of task performance in hazardous job operations
5. Support documentation describing safety cautions or practices
6. Outlining of training requirements relative to safety, etc.

(See Part 2, Systems Analysis, for the methods employed.)

Therefore, wherever a personnel subsystem effort is part of a system development program, this effort should in some degree be oriented toward furnishing detailed information and data in support of the system safety objectives.

PART 6. SYSTEM TEST

Despite careful design and component development tests, it has become increasingly obvious in the development of complex systems that independent or collaborative operational systems tests and evaluation procedures are a vital requirement to ensure the attainment of maximum safety, effectiveness, and operational capability. Special systematic operability tests should be conducted to ensure and verify the suitability of human factors provisions, the engine/GSE/personnel compatibility, and the correctness, clarity, and adequacy of procedural instructions. Equally important is the necessity for system reevaluation tests to ensure the suitability of modification kits, procedural changes, and changes of parts, materials, or source of supply. The basic objective of this task should be, therefore, the evaluation of the operational safety and reliability of the propulsion system under operational conditions.

CONTRACTOR SYSTEMS TESTS

Operability verification tests could be conducted by a specially trained test team to verify the ease of operation, servicing, handling, maintenance, and safety of the contractor's equipment. For example, special test teams may be composed of representatives from each of the following: engine development, GSE-AGE, maintenance engineering, product manual, and reliability human engineering. Operability tests should be conducted periodically on various equipment items or subsystems during all phases of use from factory to test station and, as possible, during assembly, static firing, and launch operations. Careful attention should be given to verifying and updating the technical data or procedures used in

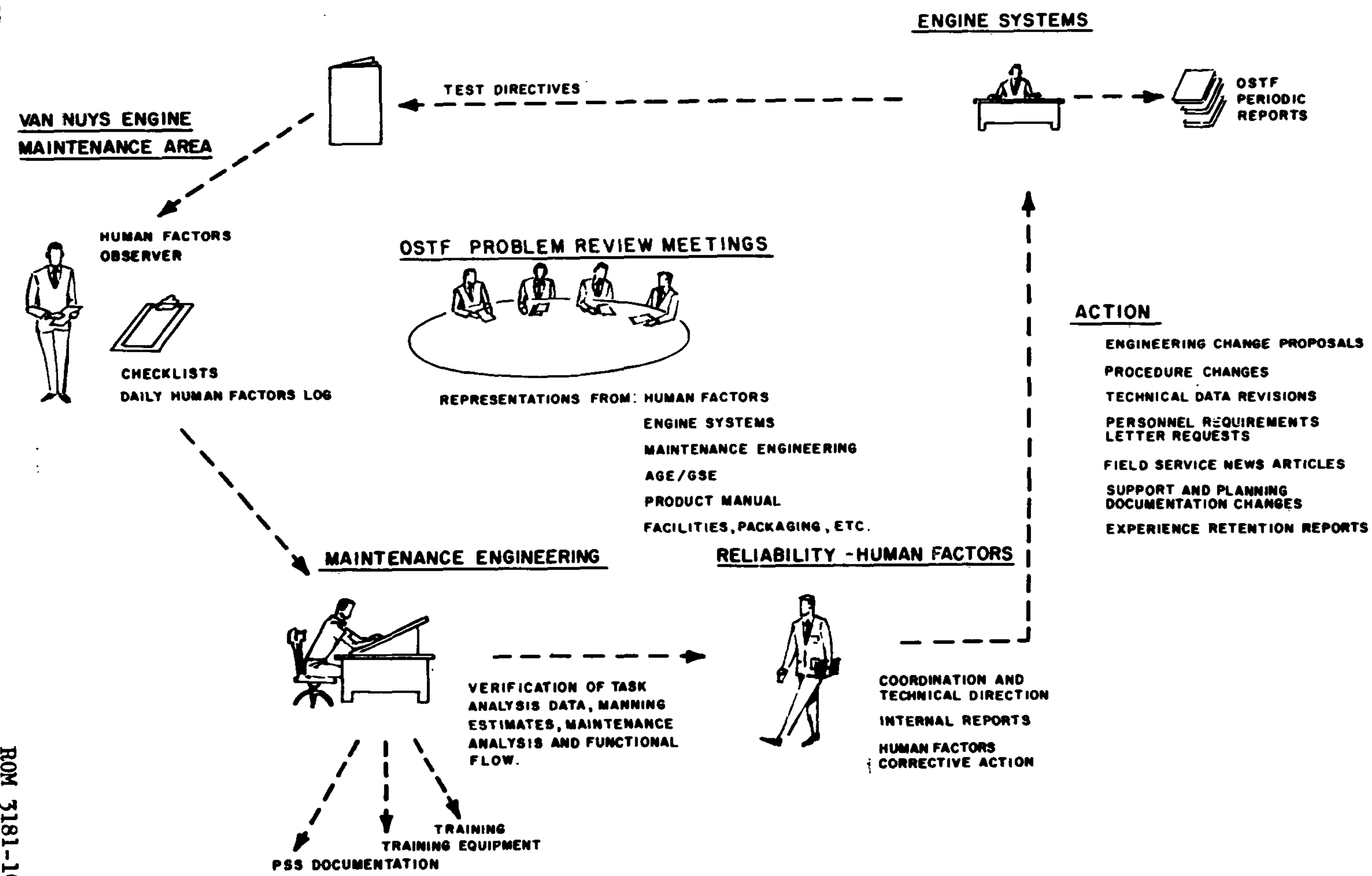


Figure 8 . EMA Human Factors Data Processing System

support of the system. The test team should be responsible for early test planning, the preparation of test directives, the gathering of data during tests, subsequent analysis, report preparation, and the requirement for posttest corrective action efforts to actually secure the indicated improvements in equipment design or procedures. The basic organization and data flow of the Atlas OSTF Van Nuys test program is shown in Fig. 8 , which illustrates one organizational approach to a maintenance demonstration program.

OPERATIONAL SYSTEMS TESTS

The collection and evaluation of human performance data during the operational usage of complex systems (such as the gathering of deviation/difficulty reports) is important in relation to six potential areas of application:

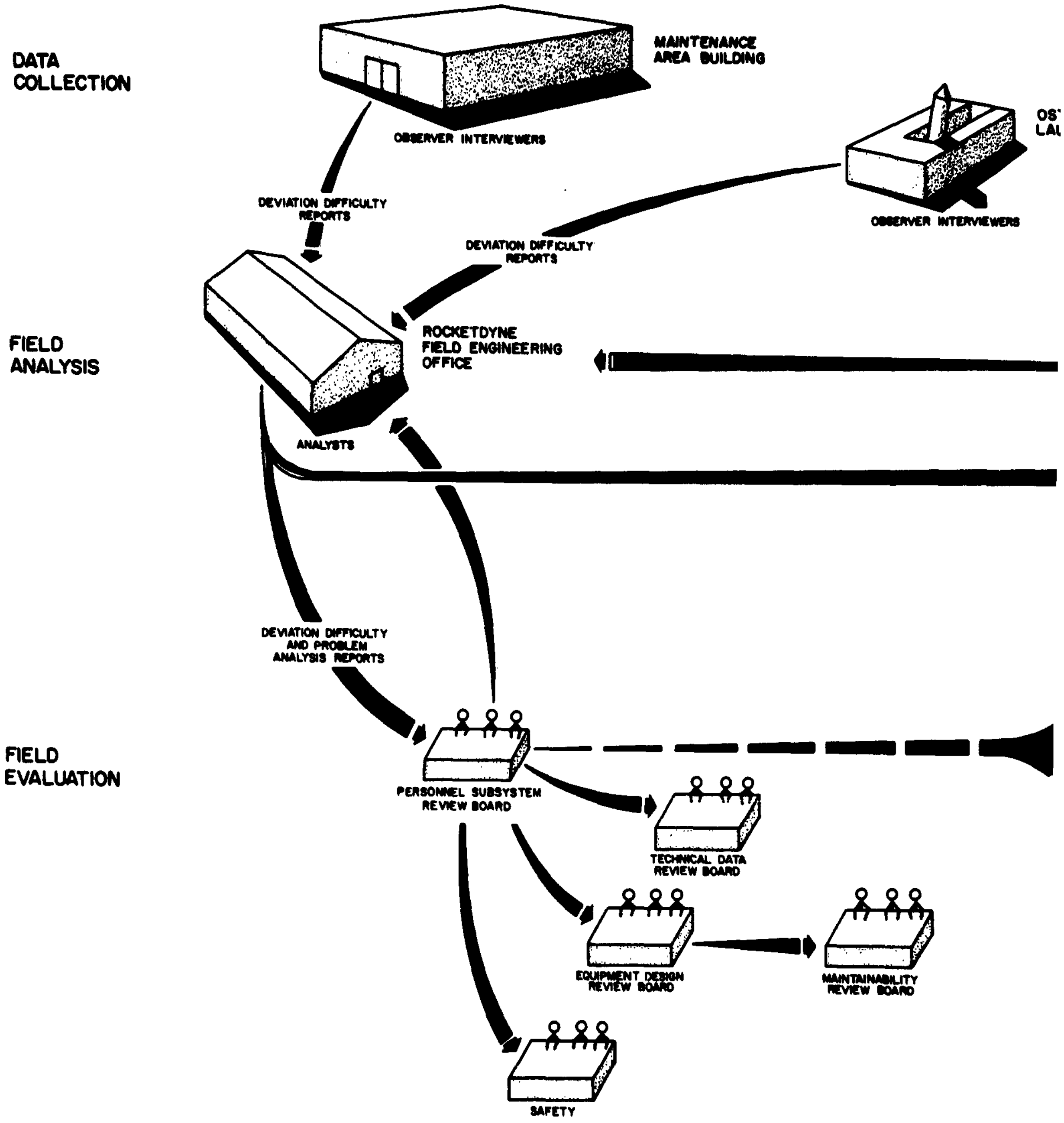
1. Identification of specific problems in order to secure immediate corrective action to upgrade the effectiveness of the system
2. Definition of general problem areas in order to ensure that preventative action can be taken on related future systems
3. Assignment of data (such as difficulty or failure reports) in some sort of implied or purposeful, haphazard, or systematic manner in order to achieve some form or type of grading process, or effectiveness rating, or merit judgment concerning various items of equipment or subsystems
4. Evaluation of data relative to various systems development phases, attainment of technical objectives, the adequacy of support services, or methods used in meeting customer requirements

5. Utilization of empirical data to verify and/or correct the logical assumptions of some prior systems analysis

6. Incorporation of representative human performance data in relatively formal or scientific mathematical models of the operational situation in order to achieve better management control, permit more effective management decisions, or attain a definable comparative evaluation of men, machines, material, and monetary expenditures relative to the over-all systems.

The method by which personnel subsystem and human factors data are used to identify and correct operational problems is readily apparent in various sections of this report. However, it has been more difficult to apply such data in rigorous systems analysis and mathematical model formulations. In fact, one of the more critical methodological problems in man-machine research is the need to develop much more realistic, useful, and appropriate mathematical models for human performance research (Chapanis, et al).

The basic data flow for the Atlas OSTF-1 and OSTF-2 VAFB programs is shown in Fig. 9 . It should be noted that a separate safety board was located close (geographically and in terms of data flow) to the source of the basic test data. Copies of all home plant reports contained a separate evaluation of test data relative to system safety, and were sent to the AF BSD safety personnel at Norton AFB for possible application to other Atlas sites.



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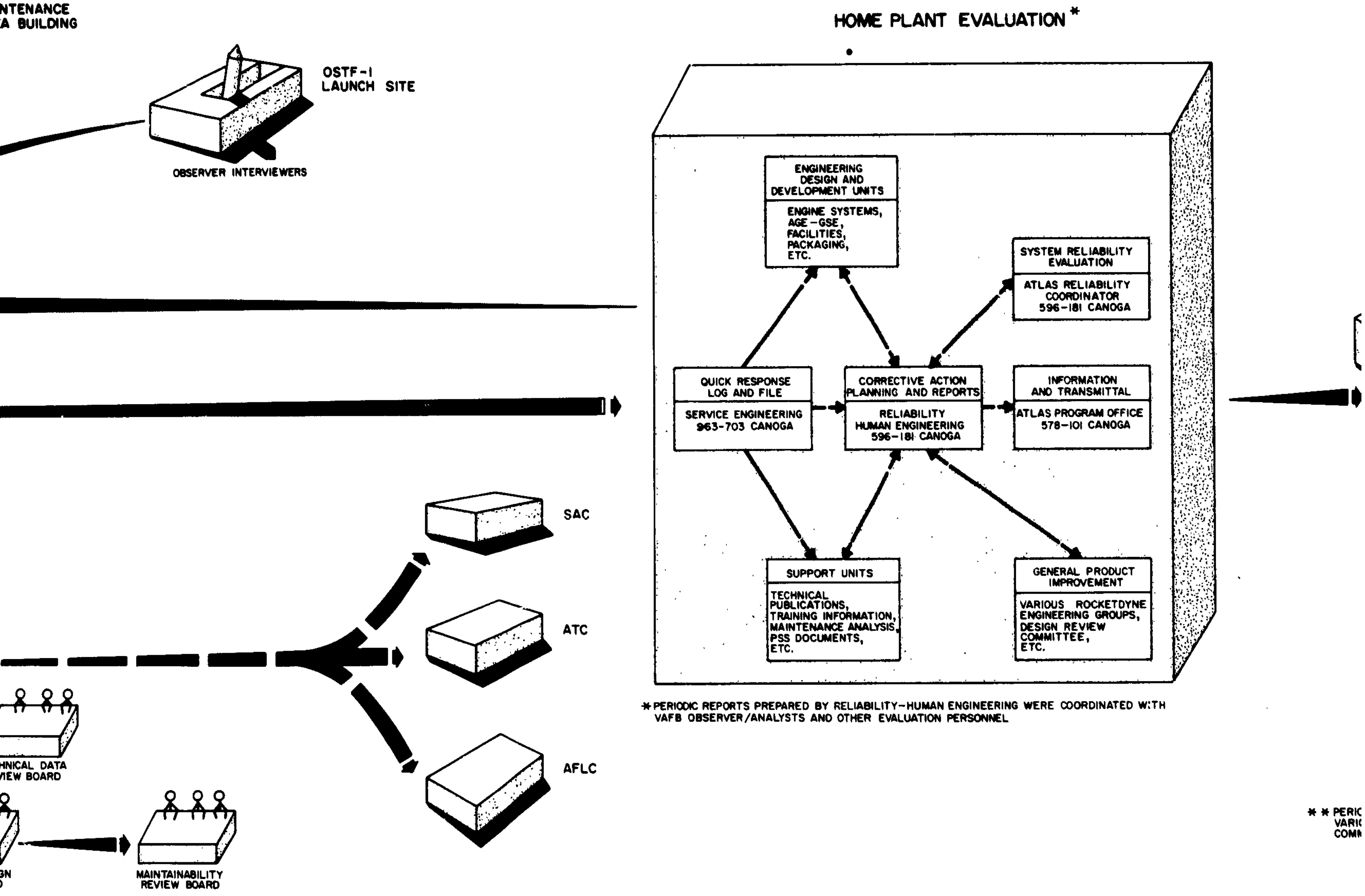

* PERIODIC REPORTS PREPARED BY RELIABILITY-HUMAN ENGINEERING WERE COORDINATED WITH VAFB OBSERVER/ANALYSTS AND OTHER EVALUATION PERSONNEL

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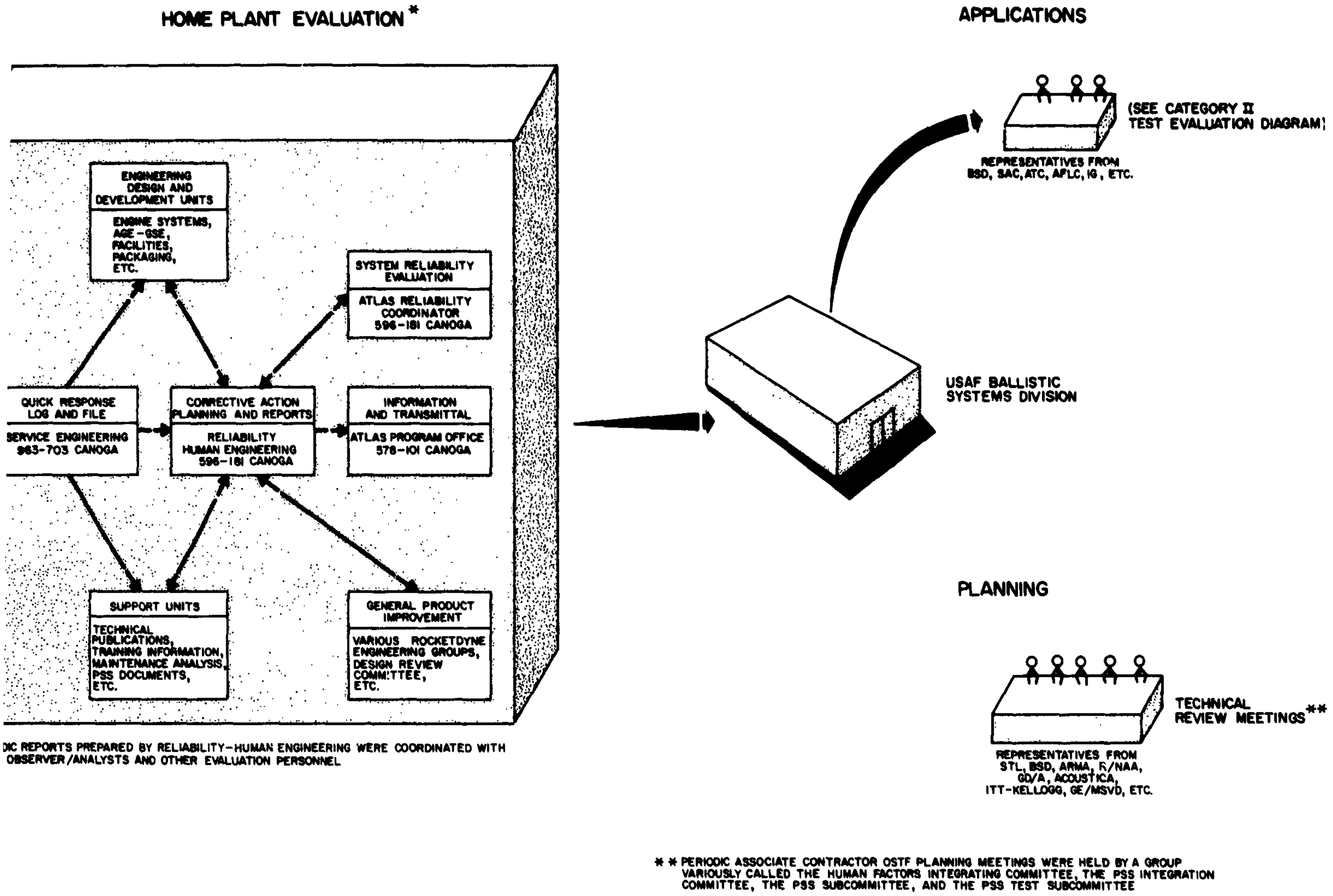


Figure 9. Personnel Subsystem-Human Factors Data Flow Chart (VAFB OSTF)

ESTIMATING PROGRESS IN THE TEST PROGRAM

During the course of the OSTF-1 test program at VAFB, it became obvious that it was extremely difficult to accurately determine the progress or completion status of the test program. At a given point of time, was the program 30 percent finished or 60 percent finished? What criteria of completion could or should be used? How could it be determined what had to be done in order to complete the necessary testing?

Periodic status completion information is important for those who make general management decisions regarding the test program (i.e., to determine how much longer the test program will or should run). Detailed status information is needed (1) to accurately forecast the actual costs of the program, (2) to properly schedule personnel assignments during and upon completion of the program, and (3) to help establish cutoff dates for program milestones and periodic data evaluations for change packages.

Detailed status completion information is, similarly, important to those involved in subsystem or associate contractor test planning. The following example will illustrate a typical situation where this information could be used. On a given day, tests may be scheduled at two different locations and only one test team is available for coverage (because of previous night shift operations, personnel sickness or leave, or priority tasks on other programs. By referring to a status completion record, it could be seen that both tests contained tasks which had been previously run. However, the tests involving one set of tasks were considered invalid and excluded from application toward demonstrating operational performance of the tasks. These tasks also required several repetitions to meet the test objectives. Therefore, these tasks required further test observation. On the other hand, the other set of tasks had been validly observed and no further testing was required relative to the subsystem test objectives (however, several further tests were scheduled because of the total system and special test requirements). Therefore, a decision could be quickly made as to the most profitable test to observe.

Planned Events

An index of the midstream progress of a test program could be derived simply by comparing the scheduled test events of the program plan with the tests already completed (i.e., if 75 of the 100 planned tests have been completed as of a certain date, this could indicate 75 percent completion). However, too literal an interpretation of this estimate would assume that each test takes an equal amount of time to accomplish, is equally difficult, and is of equal importance or criticality. This linear or equal increment relationship is rarely found in operational test programs. In addition, it assumes that the number of tests are constant when, generally speaking, the number of required tests seems inevitably to be constantly changing. In a Maintenance-in-Readiness Test Series, for example, there might be five tests scheduled of a 5-day hold operation. During the course of the test program, this might be reduced to four tests (then three tests, then two tests) as time or money runs out, difficulties are encountered, or other priority tasks accumulate. A test program could, conceivably, show rapid progress towards successful completion (using a Planned Event Index) merely by rapidly cancelling various tests. The converse is also true, that a negative progress indication may result when planned test events are added or reinstated (Fig. 10).

In conclusion, the use of the Planned Event Index by itself does not always provide a meaningful, useful, or reliable indicator of actual progress and, therefore, should be used only in conjunction with other indexes.

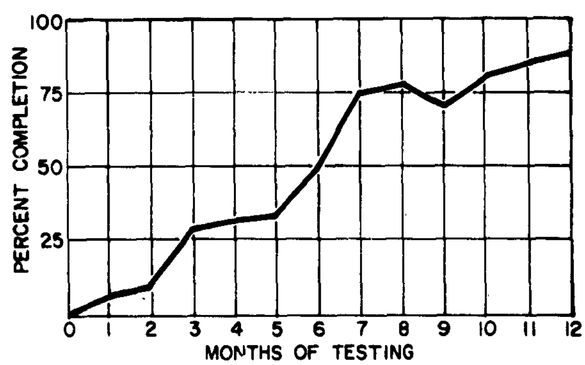


Figure 10. Planned Event Index (Illustrative)

Test Directives

Another index of test progress is provided by making a comparison of the number of test directives completed against the number of test directives written and scheduled. This differs from the Planned Event Index in that there may be several test directives written for a particular test or several test events included in one test directive.

TABLE 10

CLASSIFICATION OF TEST DIRECTIVES*

Type of Test Directive	Method of Accomplishment				
	Priority	When Accomplished	Relation to Test Delays	Required Time To Implement	Duration of Test
Standard	Mandatory	In sequence	Not applicable	Not applicable	Not applicable
Special	Mandatory	As opportunities arise, or at an appropriate point in a particular test	Could be used during a test program delay	Immediate	No limit
Priority Special	Highest Priority	As soon as possible	Not applicable	Not applicable	No limit
Supple-mental	Not Essential	When the need arises	During minor time delays	Immediate	Short time
Alternate	Not Essential	If the need arises	During major delays only	Short delay permissible	Moderate or lengthy

*Suggested classification as a result of experiences gained during the OSTF-1 Van Nuys and VAFB Programs.

The number of test directives might vary without the contractual, coordination, or over-all planning implications inherent in a change in the number of tests to be conducted. The Test Directive Index might have to be derived from a review of each type of test directive prepared (Table 10), although it could be limited to a composite of the mandatory (Standard and Special) test directives. This type of index, again, implies a linear or equal increment assignment of values which is not inherent in such a test program. In addition, Special tests undoubtedly will be added during the course of the test program and Supplemental tests may be added if test delays require such additional tests to maintain the proficiency and inertia of the test team.

Status Completion Estimated by Checklist

In view of the foregoing difficulties, the following status completion method was formulated based upon completion of detailed test objectives by checklist section.

A 100 percent completion rating was assigned to a specific checklist section for a specific test objective (Table 10) when it had been verified by testing that the equipment design, technical data, job environment, personnel selection and manning, training, organizational controls, or safety (whichever objective is being evaluated) adequately supports human performance so that the operational AF personnel can effectively operate, maintain, or control the weapon system (in terms of what was required in the checklist section).

A zero percent completion rating was assigned when the testing did not verify the adequacy of this support. Some of the test conditions which would result in a zero percent completion status for one or more objectives are:

1. The test was not performed (all objectives).
2. PSS observers did not observe the test performance (all objectives).
3. Major deviations from operational procedures were employed (technical data and, sometimes, others).
4. No attempt was made to use operational equipment (equipment design and, sometimes, others).
5. Operational crew complement and composition was not observed (personnel selection and manning, training, and, sometimes, others).
6. Operational controls were not used, or were severely adulterated with contractor organizational controls (organizational controls, and, sometimes, others).
7. Major deviations from safety standards were consistently employed (safety, and sometimes, others).

A 50 or 75 percent completion rating was assigned when the adequacy of this support had been only partly verified (i.e., major problems have been identified, showing that the support is not adequate in some particular respect and that these problems have been reported by deviation/difficulty or incident reports).

A 50 percent rating is given when either of these conditions exists:

1. No corrective action has been determined.

   NOTE: If the recommended corrective action is rejected and no suitable alternate is initiated, for all practical purposes no corrective action has been determined because the inadequacy still exists.

2. There are indications of other major problems which have not yet been adequately identified.

A 75 percent rating is given when either of these conditions exists:

1. Corrective action for major problems has been determined previously and accepted, but it has not been demonstrated by testing that the corrective action does correct or control the problem without creating additional major problems.

   NOTE: This is not the same as corrective action across the weapon system, which is not a Category II requirement.

2. Corrective action has been tested, but the extent of the control or elimination of the problem is marginal; further testing is required for assurance that the support of human performance is adequate under all conditions which may be encountered during operational use.

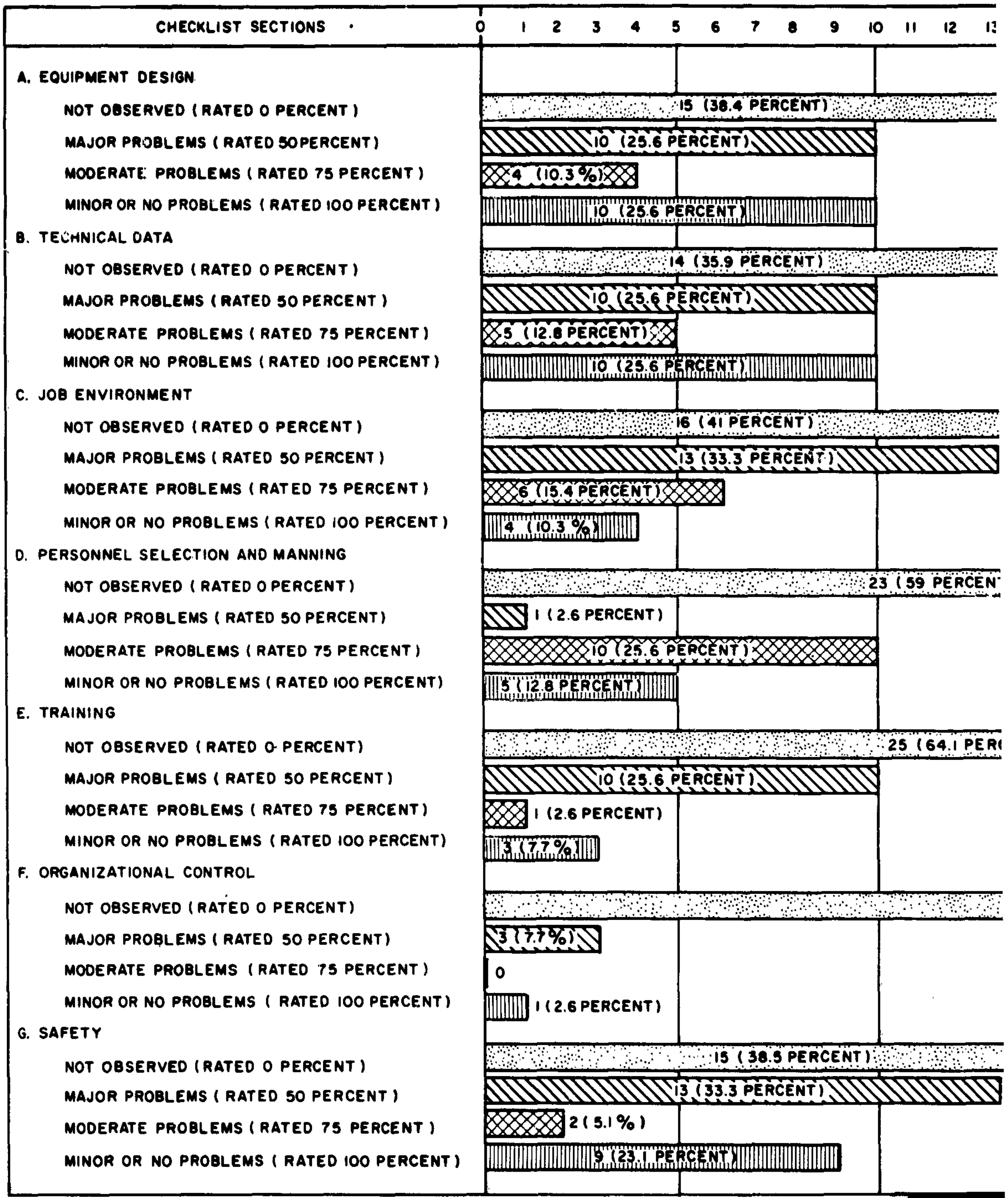
This detailed method is termed the Qualitative Checklist Method because of the emphasis on fidelity of test conditions and effectiveness of corrective action proposed.

For purposes of comparison, another approach (Quantitative Checklist Method) to the estimation of status completion would be simply the assignment of a 100 percent completion rating when the following conditions are met:

1. The test was observed.
2. Major problems were reported.
3. Corrective action was recommended.

For this same level of accomplishment, the Qualitative Checklist approach would be to assign a rating of from zero to 100 percent complete (depending upon how well the objective conditions of the test directive were achieved and how successful were the efforts to obtain corrective action). In general, the Qualitative Checklist completion ratings are consistently lower than those made by the Quantitative Checklist approach.

The Qualitative Checklist DTO completion ratings will meaningfully indicate where Category II will overlap into Category III, i.e., where the using activity must apply additional effort to upgrade the weapon system to full operational effectiveness. Any area which shows less than 100 percent completion at the end of such testing will require additional Category II type of activity during Category III use (Fig. 11 and Table 11).



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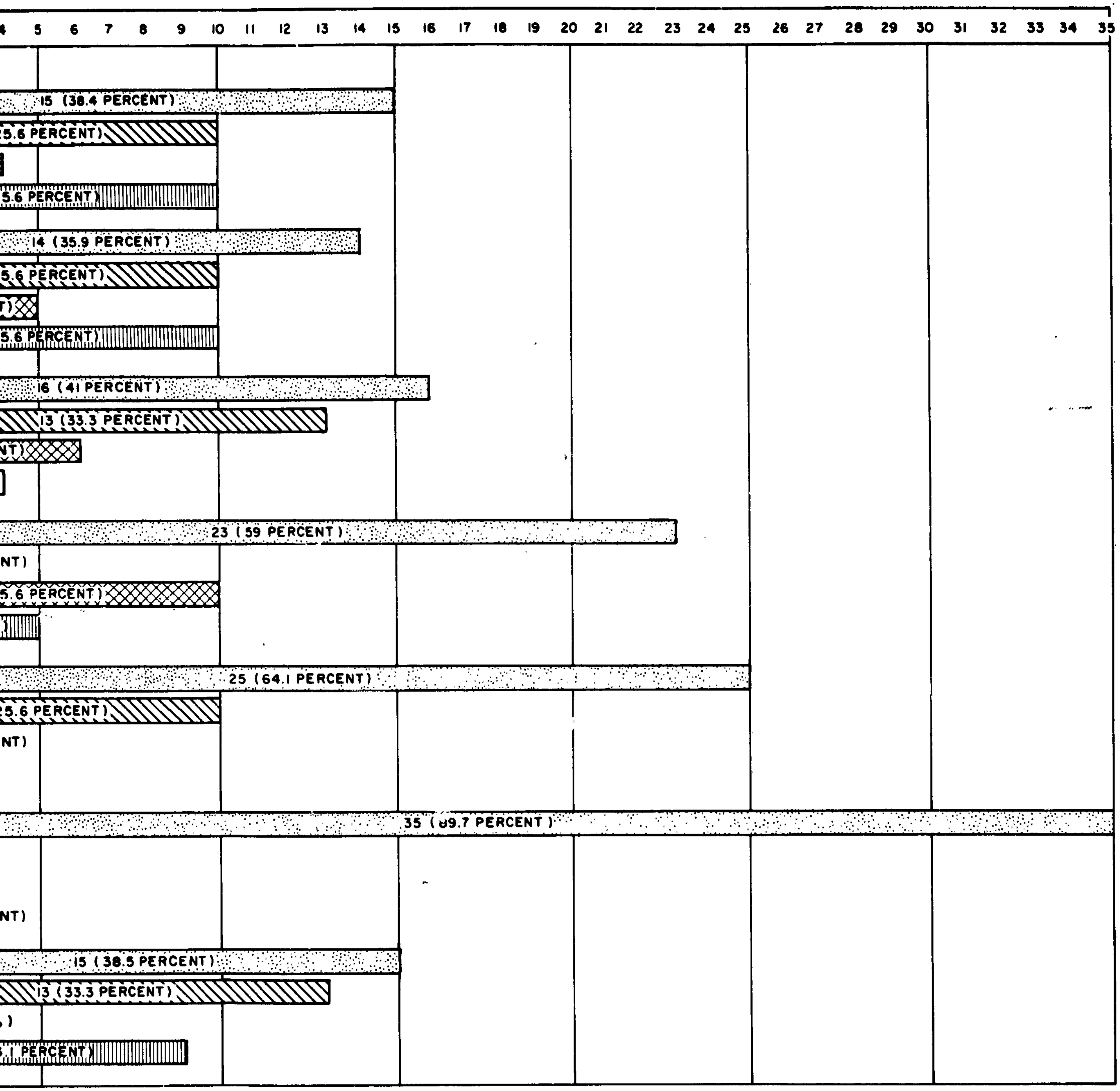

Figure 11. Analysis of DTO Completion Status Ratings

TABLE 11

DTO STATUS COMPLETION BY

Tasks	Reference	Minimum Runs Required for R-PSS	Total Runs Scheduled	Total Runs Made to 30 July 1962	Full or Partial Exclusions	Equipment Design, Percent	Technical Data, Percent	En
Missile Flight Control System Checkout Lubricate Engine Gimbal Bearings	Section 14 page 14-2	2	6	2 (33 percent)	2	100	100	
Missile Frequency Response Check	Section 15 pages 15-2 and 15-3	2	6	2 (33 percent)	2	100	100	
Vernier Engine Solo System Leak Check	Section 21 pages 21-7 through 21-48	2	6	4 (67 percent)	4	75	50	
Sustainer Engine System Leak Check	Section 22 pages 22-1 through 22-51	2	6	5 (83 percent)	4	75	75	
Booster Engine System Leak Test	Section 23 pages 23-3 through 23-38	2	6	4 (67 percent)	4	100	75	
Missile Ordnance Circuit Resistance Tests	Section 24 pages 24-11 through 24-23	2	6	3 (50 percent)	1	100	100	
Sustainer Turbopump Preservation	Section 25 pages 25-1 through 25-17	2	6	1-3/4 (30 percent)	3/4	75	75	
DTO Completion for CL-7-3 average				(38 percent)		73	68	
Tasks at Launch Area (OSTF-1) Missile Installation	T.O. 21-SM65E-CL-12-2 26 January 1962							
Remove Booster Actuator Locks, Sustainer Transport Strut; Install Blowoff Covers and Desiccants	Section 10 pages 10-1 through 10-4	2	1	4 (100 percent)	4	50	50	
DTO Completion for CL-12-2				(100 percent)		50	50	

TABLE 11

DTO STATUS COMPLETION BY CHECKLIST

Runs e to ' 1962	Full or Partial Exclusions	DTO Completion Status							Operations Required to Achieve Category II PSS Test Objectives	Are These Operations Scheduled?
		Equipment Design, Percent	Technical Data, Percent	Job Environment, Percent	Personnel Selection and Manning, Percent	Training, Percent	Organizational Control, Percent	Safety, Percent		
rcent)	2	100	100	75	100	100	0	100	Run twice using AF personnel, AF SOP, and 90-degree fitting from AF supply (and not a VAFB-peculiar fitting)	No
rcent)	2	100	100	75	100	100	0	100	Same as above	No
rcent)	4	75	50	50	0	0	0	50	Run twice using AF personnel AF SOP, verified technical data, proper hand tools, lighting, work platforms, and with latest TD and ED changes incorporated.	Yes
rcent)	4	75	75	50	0	50	0	50	Run using AF personnel, AF SOP, better lighting, adequate hand tools. Compare VAFB-peculiar adapter with operational configuration; use work platform, modified test plate (G 3087)	No
rcent)	4	100	75	50	0	0	0	50	Run twice using AF personnel, AF SOP, thrust chamber protective pad, safe work platforms, and a complete G 3080 plates and plugs kit	Yes
rcent)	1	100	100	50	100	100	100	100	Make available torque-set screwdriver tips	Yes
-3/4 rcent)	3/4	75	75	100	100	0	50	100	Modify engine lube oil drain line, then run using AF personnel and AF SOP	No
rcent)		73	68	55	50	45	25	65		
4 percent)	4	50	50	50	75	50	0	50	Color code locks, strut; expand MMT's propellant system training; revise access routes and platforms; complete revision to P-4 technical data, then run twice using new MOCAM crew (one MET/M), AF SOP, adequate tools, lighting, and jack or hoist to lift thrust chamber	No
percent)		50	50	50	75	50	0	50		

2

TEST EVENT: No. R-31 Title [illegible]

PLANNING INFORMATION

Test Series Code: I-3-1-A

ITI BLS-157 FFC 27-1362 TAWS 50004

Applicable Logical Function: [illegible] area

Site OSTF-1 Launch Area

O&M Checklist T.O.21-SM65E-CL-7-3, 27 Dec. 61

Personnel Performance Checklist none

Test Directive ESG-697C (15 [illegible] 62)

TIME AND PERSONNEL

Date Started: 0700 [illegible] 17 May 62

Date Completed: [illegible]

Analyst [illegible]

Observer [illegible]

Participants [illegible] 47351A
[illegible] 44371A

TEST DATA ACCRUED

Deviation/Difficulty Reports D/D 3572R D/D 3577R

Problem Analysis Reports PAR 37-R, [illegible]

Operation and Failure Reports R 12092

Personnel Subsystem Change Requests PSCP MA3-15

Publication Change Requests PCS A-134-1445

ECP/MCR Action None

RELEVANT REMARKS

Pending Action Capt. [illegible] AFLC [illegible] grease gun fitting [illegible]

Significant Time Delays or Other Incidents [illegible] necessitated re-run of MAPCHE [illegible] 237. [illegible]

If Exclusion, * Reasons Why fitting [illegible] Non-standard [illegible] grease gun fittings were [illegible]

Other Remarks Verify whether [illegible] fitting [illegible]

*An exclusion is a test event which is not applicable or is nonrepresentative of an operational test event.

Figure 12. Illustrative Test Event Log Sheet

Comparison of Status Completion Methods

1. Planned Event: Tests completed/tests scheduled in program plan
2. Test Directive: Test directives completed/test directives formulated and scheduled
3. Quantitative Checklist: Checklists actually completed/checklists scheduled
4. Qualitative Checklist: Checklists appropriately evaluated/checklists scheduled

TEST DATA CONTROL

Immediately following each day's testing, a Test Event Log sheet should be prepared for each completed identifiable test event. If this is not done, a review of the available test records after several weeks of elapsed time could be misleading (i.e., the test directions may not have been followed, or followed only in part because of shortages, aborts, or unusual circumstances). Therefore, it would be difficult to assess in detail which test events were validly performed, which were omitted for some reason, or which should be treated as exclusions when evaluated against test objective criteria.

An Illustrative Test Event Log sheet is shown in Fig. 12. It is based upon the experience gained during both the EMA and VAFB test programs and it constitutes what is felt to be a vital test data control feature in system test programs. Future test programs might require modified versions of this log sheet. While the format may change, the content be varied, the form integrated with other forms, the need for such a daily record is basic to the conduct of any test program.

In the control of test data, there are five other features which are of vital importance to the accomplishment of a successful test program:

1. There should be no immediate screening or restrictions on the recording of test data. Restrictions are implicit in such remarks as:

   a. "Don't report that kind of a problem."

   b. "Everyone already knows about that."

   c. "We'll handle that ourselves."

   d. "That's no problem."

   It should be clearly understood by all observers that all data should be immediately recorded without restriction or limitation.

2. Some protection should be afforded to the data collector so that he may record all data, however crude or incomplete, for subsequent analysis. A requirement for perfect, defensible, raw data may result in significant data going unrecorded because of some minor flaw, confusion, or uncertainty. Every problem seen should be recorded and described as accurately and completely as possible, even though some organizations or individuals may not approve of the generation of such information.

3. Raw data should move rapidly through the primary data analysis system. There should be no orifices, biases, or liability to the data generator (observer) other than to report as accurately and completely as he can. The primary data analysis system includes home plant analysis by those who are part of the program test team.

4. The basic assumptions, purposes, and guiding philosophy of the over-all test plan must be clearly understood and maintained throughout the test program (against the wide fluctuations which can occur during an extended period of time in a large-scale test program). Section 6, Part 2, Application to Human Performance Evaluation, contains further information concerning the fundamental nature of system test efforts.

5. The importance of appropriate and timely test directives was previously described in Rocketdyne Report R-3520, OSTF Test and Evaluation Program for the Atlas MA-3 Engine Maintenance Area, May 1962 (Part 2, Program Management, 15-67). The importance of adhering to the established test directive is adequately described in several of the case studies (Section 2 of this report).

PART 7. SAFETY SURVEILLANCE TEAMS

One approach to the identification of potential safety problems could involve the use of Safety Surveillance Teams. The objective would be to provide an independent means through which program engineers, project engineers, and other responsible supervision can operationally investigate, find causes, and determine solutions to reliability problems of a safety nature which appear to be acute, chronic, or interorganizational in nature.

Occasionally, this may be necessary in order to complement the activities or gain supporting information from (or for) inplant safety committeeman organization or an operational-site failure reporting system. It may also serve to provide a means for monitoring or maintaining surveillance as to the effectiveness of a more extensive or scheduled safety reporting system. However, it is more often needed to intensively investigate, to realistically identify, and to find solutions to problems affecting equipment and processes which cannot be satisfactorily solved by other methods.

The distinguishing feature of this approach is the effort to effectively identify and resolve problems on a grass root or local level. Many of these safety problem areas involve, to some degree, the basic motivation or fundamental attitude held by direct working personnel and first-line supervision. This approach accurately determines, isolates, investigates, and solves these safety problems in a more immediate, direct, and knowlegeable fashion than might otherwise be the case. It is a general management technique for handling a class of safety problems and provides direct information on both specific or organization-unique problems and inter-organization or interface problems. The scope could conceivably include efforts in various organizations or departments, such as Engineering, Manufacturing, Material Procurement, Quality Control, Test, Logistics, Field Service, maintenance or checkout areas, launch sites, or missile assembly points.

The implementation of such an approach might involve formation of temporary Safety Surveillance Teams consisting of an experienced safety or reliability engineer, a human factors engineer, a department leadman or supervisor, and a direct working person. These teams could meet periodically in various locations while a particular safety problem, function, or area is being investigated, while corrective action is being determined, or while the effectiveness of various changes in procedure or design is being assessed.

PART 8. DESIGN REVIEW

An audit team, functionally independent of the responsible design and development groups, can provide an effective design review activity which could consider safety as one of the major design criteria. The design review committee may be composed of senior level engineers supported by various technical specialties (including those which can contribute to a detailed system safety engineering evaluation).

The design review may occur at several logical checkpoints. Examples are:

1. Preliminary review of proposed design concepts
2. Critical review upon completion of formal layout to evaluate design details
3. Final review prior to the release to production or tests

The design review committee may, for example, utilize design checklists, static and dynamic analyses, malfunction studies, material and stress studies, component evaluation test data, and information on the effects of environmental extremes.

The formal design review process provides greater assurance of:

1. Use of the best possible design practices, standards, and preferred parts
2. Employment of all applicable past experience, IDEP and failure report information, and previous development test data

3. Focusing of all appropriate design services talent and specialty disciplines on each drawing
4. Full consideration of system safety engineering recommendations at crucial points in the design process

PART 9. CATASTROPHIC ANALYSIS

A thorough analysis of all possible failure modes, causes, and effects should be made to render failure less probable and less critical through redesign, use of derating, redundancy, use of malfunction detection systems, fail-safe design features, etc. Such catastrophic analysis information should be regularly used in the design review activity to evaluate the acceptability of proposed designs. It should also be used by design groups in determining tradeoffs between alternative design paths. It also serves to determine and focus attention on design areas where some modification could result in a significant gain in reliability.

Catastrophic analysis information is available from reliability malfunction analyses or failure effect analyses. Malfunction analysis is a detail design drawing analysis of all probable failure modes, their causes, and their consequences. Failure effect analysis is a detail drawing analysis of all possible system failures and their consequences. In the process of attempting to achieve a manrated design, special attention has to be paid to personnel safety factors during malfunction or failure effect analyses.

The search for design weakness involves the listing of all possible modes of failure and the stress conditions which might induce failure under the anticipated operational environment. The system consequences of each mode of failure are described. A quantitative prediction of the likelihood of failure can be derived from applicable related experience on similar elements, components, or subsystems. Such failure mode predictions can serve as a basis for formulating detail test objectives and statistical test design planning efforts.

Any significant critical failure which could cause a mission failure should receive special safety design attention relative to counteracting all hazardous consequences. (See Section 3, Parts 1 and 2, dealing with Safety Criticality Rating.)

APPENDIXES

APPENDIXES

APPENDIX A

GLOSSARY

The following terms are defined in accordance with their usage in this report. Only those terms found to have some inherent ambiguity or very specific meaning are defined. Emphasis is given to terminology which is new or particularly germane to the report content.

Achieved reliability: the reliability demonstrated, at a particular point in time, under certain specified conditions

Bachelor time: the accumulation of hours, minutes, and/or cycles on an item of equipment before delivery to the customer when it is not installed in its OCL assembly

Calibration: comparison of an instrument or device with another, which is of known accuracy, to detect or adjust the accuracy of the instrument being compared

Cannibalization: removal of needed parts from a similar system or assembly for installation on another system which is being repaired or modified

Compatibility: that particular quality of characteristics of a model which assures its ability to function effectively with other models of the system

Category II testing: development testing and evaluation of the complete system, i.e., the integrated subsystems, to determine if the theories, techniques, personnel skills, material, and items of equipment are technically sound, safe, reliable, and meet established specifications and operational requirements (It is a joint contractor-customer effort, with gradually increasing customer participation.)

Checkout: any sequence of operational and calibrational tests which could provide information necessary to determine the condition and status of an item of equipment

Configuration: the composition or listing of the serially coded noninterchangeable part numbers or names of a model

Deviation difficulty: any incident which occurs outside the standard, predicted, or expected template of human behavior (such as excessive time to complete a task, an indentifiable difficulty in performing an assigned task, any pattern of behavior which could lead to undesirable system performance characteristics, or any act which leads to a human-initiated failure)

Down time:	the sum of the active maintenance down time, supply down time, waiting down time, and other lost time during which the system is not in a condition in which it can perform its intended function.
Effectivity:	date of effective change
End item:	a final combination of products, component parts, and/or materials which is ready for its intended purpose (e.g., turbopump or rocket engine)
Failure analysis:	a detailed study or analysis to determine the cause or mechanism of failure
Fail-safe:	self-checking features which will cause a function to cease and return to hazard-free condition in case of failure, malfunction, or out-of-tolerance drift
Failure:	inability or an item to perform its required function or any reportable physical, electrical, mechanical, or electromechanical deviations from the controlling specifications
Human error:	(see definition in Section 5, Part 1, Operational Definition)

Human-initiated failure: any malfunction, failure, damage, or delay which is directly traceable to improper or faulty acts of commission or omission (including such things as incorrect adjustments, activation of wrong control incorrect wiring, and improper handling)

Inherent reliability: the potential reliability present in a design (This would be the probability of equipment operating properly under the contractually stated operational conditions, utilizing, in the manner intended, the required supporting equipment, procedures, personnel, and controls.)

Inherent safety: the potential safety present in the design or features of the design (See inherent reliability.)

Inspection: the process of comparing an item with the applicable requirements by examining, measuring, testing, or gaging

Interface: a point between subsystems where appropriate matching, compatibility, or accommodation must be attained to ensure proper operation relative to all other functional entities in the system (to achieve the purpose of the project or mission)

Item: an all-inclusive term which may refer to parts, subassemblies, assemblies, accessories, or equipments

Maintainability:	the resultant of those factors of the equipment, as installed, which facilitates accomplishment of maintenance tasks with minimum time, skill, and resources. (See definition in Section 1, Part 3.)
Malfunction:	any occurrence of unsatisfactory performance
Maintaining:	a term including work tasks related to inspection, servicing, repairing, and testing as to serviceability where the objective is to retain or restore equipment serviceability (It may be scheduled (preventive) or unscheduled (corrective) in nature and may be assigned as an organizational, field, or depot responsibility.)
MD number:	a compound term consisting of letters and figures which, when used with a Model Designation, indicates the configuration of a model, and from which its compatibility with other models in the same system may be ascertained by reference to supporting documentation
O&M checklist:	detailed checklists used to perform operations and maintenance on the system at the operational site (GD/A Report AP60-0967, Style Guide for Preparation of Operational Checklists for WS 107A-1, Atlas Series E, 1 December 1960, gives illustrative details of preparation.)

Operational: the status of a system which permits its use by field or customer personnel in its intended environment

Operating: a term including tasks of activating, monitoring, regulating, or changing the performance of an item of equipment by means of controlling devices

Organizational controls: (See definition in Section 1, Part 3.)

Production model: an equipment model in its final production form and design which is made by production tools, jigs, fixtures, methods, and processes

Periodic inspections: regularly scheduled repetitive inspections (based on specific calendar periods or operating time) to ensure that equipment is in readiness to operate satisfactorily and to identify conditions which could possibly degrade systems performance

Process: the procedure or technique followed in the production of a product

Prototype: an equipment model which is suitable for use in the preliminary evaluation, design, form ana performance of the production equipment

Preliminary design:	the design phase during which the basic configuration and performance of a system is established
Preventive maintenance:	the periodic checking, inspecting, or reconditioning of a system to identify or reduce possible deterioration of performance and to detect and correct incipient malfunctions before they can develop into failures
Quality control:	an operation oriented toward assuring the manufacture of a uniform product, within specified defect limits, in accordance with the design intent as described in engineering drawings, specifications, and requirements
Reliability:	the probability that an item will perform a required function under specified conditions for a specified period of time.
Safety:	(See definition in Section 1, Part 3, Safety.)
Servicing:	work tasks of lubricating, filling, bleeding, purging, draining, preserving, cleaning, packaging, and storing
Simulation:	a set of test conditions designed to closely approximate some phase of the field operating or usage environment

System effectiveness: the probability that a system can successfully meet an operational demand within a given time when operated under specified conditions

Time-significant item: an item which is degraded as a result of usage and/or calendar age

Time-compliance technical order: directives issued to provide instructions for accomplishing one-time changes, modifications, inspections, or installation of equipment

APPENDIX B

ABBREVIATIONS USED IN THIS REPORT

AFBSD	Air Force Ballistic Systems Division (formerly AF Ballistic Missiles Command)
AFLC	Air Force Logistics Command (formerly Air Material Command)
AFQC	Air Force Quality Control
AFSC	Air Force Specialty Code or Air Force Systems Command
AGE	Aerospace Ground Equipment (formerly GSE)
ATC	Air Training Command
APIN	Atlas Propulsion Information Notice
BMAT/S	Ballistic Missile Analyst Technician/Specialist (AFSC 312X4C on Atlas E Series; 312X4D on Atlas F Series)
CCB	Change Control Board
CL	Checklist
CRL	Change Recommendation Letter

D/D	Deviation/Difficulty Report (VAFB OSTF Program)
DPL	Dual Propellant Loading
D/R	Difficulty Report
ECAG	Equipment Change Analysis Group (Norton AFB)
ECP	Engineering Change Proposal
EDRB	Equipment Design Review Board
EMA	Engine Maintenance Area
FCDR	Failure and Consumption Data Report (Rocketdyne Form 609-P)
FFC	Functional Flow Charts
GSE	Ground Support Equipment (also called AGE)
GD/A	General Dynamics Corporation, Astronautics Division (formerly Convair)
GI	Government Issue
GG	Gas Generator
GN_2	Gaseous Nitrogen

HS	Head Suppression or Human Subsystem
HPU	Hydraulic Pumping Unit
IR	Inspection Rejection Procedure
IOL	Interoffice Letter (Rocketdyne)
ITI	Integrated Task Index
LER	Large Engine Report (Rocketdyne)
LFSMT/S	Liquid Fuel Systems Maintenance Technician/Specialist (546X0A, formerly 568X0B)
LO_2	Liquid Oxygen
LR	Prefix to Engine Model Number Indicating "Liquid Propellant Rocket Engine"
LP	Launch Platform
MAPCHE	Mobile Automatically Programmed Checkout Equipment
MCR	Master Change Record
MDL	Master Deficiency Log (maintained by VAFB AFQC)

MET/M	Missile Engine Technician/Mechanic (443X1A, formerly 433X1)
MET/S	Missile Electrical Technician/Specialist (441X0A, formerly MERT/R, 423X0)
MFT/S	Missile Facility Technician/Specialist (421X3)
MMT	Missile Maintenance Technician (443X0A, formerly 433X0)
MPRT/R	Missile Pneudraulic Repair Technician/Repairman (442X0A, formerly 421X2)
MAB	Missile Assembly Buildup
MAMS	Missile Assembly and Maintenance Shops
MRB	Maintainability Review Board
NCU	Nitrogen Charge Unit
OJT	On-the-Job Training
OSTF	Operational Systems Test Facility
ORT	Operational Readiness Training
P/N	Part Number

PAR	Problem Analysis Report
PCS	Publication Change Suggestion (Rocketdyne form)
PECP	Preliminary Engineering Change Proposal
PETS	Position-Equipment Task Summary
psig	Pounds per Square Inch, gage pressure reading
PSS or PS	Personnel Subsystem (see, also, HS)
PSRB	Personnel Subsystem Review Board of the OSTF Task Working Group (formerly PSSRB)
PTD	Program Test Director
PU	Propellant Utilization
QD	Quick Disconnect Fitting
RC	Prefix to Rocketdyne correspondence control number
REM	Reliability Engine Memorandum
RFB	Reliability Function Block
R/NAA	Rocketdyne, a Division of North American Aviation, Inc.
ROM	Reliability Operations Memorandum (Rocketdyne)

R&R	Remove and Replace
RERB	Rocket Engine Relay Box
SAC	Strategic Air Command,
SBAMA	San Bernardino Air Material Area
SC	Site Commander
SOP	Standard Operating Procedure (for an Air Force squadron)
STL	Space Technology Laboratories, Inc.
SMA	Squadron Maintenance Area
SPGG	Solid Propellant Gas Generator
SPO	Systems Project Office
STOC	Standard Tactical Operational Condition
TAWS	Task Analysis Worksheets
TCTO	Time Compliance Technical Order
TDRB	Technical Data Review Board

TMCR	Technical Manual Change Request (GD/A equivalent of Rocketdyne PCS)
TO	Technical Order
TWSG	Test Wing Safety Group
VAFB	Vandenberg Air Force Base
VE	Vernier Engine

APPENDIX C

SAFETY PROBLEM TABULATION AND CROSS-REFERENCE INDEX

Type of Problem	Human Factors Problem No.
Potential Engine Failure	98, 211, 216, 276, 290
Equipment Design	
Maintainability	60, 235
Operability	19, 57, 71
Functional Deficiency	57, 86, 88, 129, 140, 148, 206, 236
Susceptibility to Damage, Deterioration, or Cannibalization	206, 223, 276
Technical Data	
Crutch for Equipment or Organization	98, 121, 235
Omissions	140, 199
Job Environment	
Falling or Tripping Hazard	16, 85, 98, 129, 213, 216, 223, 235, 255, 262, 302
Electrical Shock Hazard	60, 71, 86, 206
Pressure or Explosion Hazard	86, 111, 155, 168, 274, 279, 291
Fumes	148, 154, 279
Other	88, 237, 243
Impaired Functioning of Safety Feature	248, 272, 274, 283, 285, 291
Fire Hazard	155, 279, 284, 285
Personnel Selection and Manning	230
Training	
Job Knowledge	111, 155, 223, 227, 279
Job Skills	213, 223, 230, 288, 302
Work Habits	121, 168, 206, 231, 252
Attitudes	98, 154, 166, 216, 285

APPENDIX C
(Continued)

Type of Problem	Human Factors Problem No.
Organizational Control	
Need for New Controls	121, 155, 166, 216, 230, 283
Existing Controls not Adequate	98, 168, 213, 230, 231, 279
Use of Nonauthorized Equipment, Procedures, or Personnel	154, 211, 216, 223, 230, 243, 272, 274, 276, 285, 288, 290, 291, 302
Technical Representative Utilization	230
Provisioning	98, 129, 148, 221, 235, 255, 262
Manufacturing Error	284

APPENDIX D

PRODUCT TABULATION AND CROSS-REFERENCE INDEX

Rocketdyne Products	Human Factors Problem No.
Engine Hardware	
Booster Engine	98, 154, 211, 216, 230, 231, 252, 276, 285, 291, 302
Sustainer Engine	231, 274, 284, 285, 291
Vernier Engine	223, 285, 290, 291
Loose Equipment	None
Pyrotechnics	199, 227, 283, 285
Hypergolics	283, 284, 285
Technical Data	111
AGE	
G3080 Booster Plates and Plug Kit	88, 291, 302
G3087 Sustainer Plates and Plug Kit	88, 111, 291
Engine Covers and Closures	274, 276, 285
Adapters	57
G2000 Service Unit	19, 60, 71, 85, 86
G3077 Test Stand	86, 288
9011565 Thrust Chamber Pad	211
EMA Facility Design	None

APPENDIX D
(Continued)

Non-Rocketdyne Products	Human Factors Problem No.
Missile Hardware	283, 285
GD/A Technical Data	
T.O. 21-SM65E-CL-3-3	98
CL-7-3	98
CL-12-2	98
CL-13-2	98
CL-14-2	98
CL-15-2	140, 166
CL-17-2	166
CL-17-3	121
CL-21-2	98, 199, 235
Launcher Facility	129, 140, 155, 272, 279
MAMS Facility	206, 223, 237, 248
Launcher AGE	148, 168, 235, 236, 255
MAMS AGE	16, 213, 216, 221, 262, 288, 290
Communications System	121, 166
Safety Equipment	154, 243, 283, 285

APPENDIX E

LIST OF RELATED HOME OFFICE REPORTS

Rocketdyne home office reports containing Personnel Subsystem-Human Factors evaluations, submitted under the OSTF Program, are listed by month.

1960:	December	R-2831-1, Monthly Progress Report for OSTF-1 Program EMA Testing, October and November 1960 (28 December 1960), Van Nuys OSTF
1961:	January	R-2831-2, Monthly Progress Report for OSTF-1 Program EMA Testing, December 1960 (15 January 1961), Van Nuys OSTF
	February	R-2831-3, Monthly Progress Report for OSTF-1 Program EMA Testing, January 1961 (15 February 1961), Van Nuys OSTF
	March	R-2831-4, Monthly Progress Report for OSTF-1 Program EMA Testing, February 1961 (15 March 1961), Van Nuys OSTF
	April	R-2831-5, Monthly Progress Report for OSTF-1 Program EMA Testing, March 1961 (15 April 1961), Van Nuys OSTF
	May	R-2831-6, Monthly Progress Report for OSTF-1 Program EMA Testing, April 1961 (15 May 1961), Van Nuys OSTF

	June	R-2831-7, Monthly Progress Report for OSTF-1 Program EMA Testing, May 1961 (15 June 1961), Van Nuys OSTF
	July	R-2831-8, Monthly Progress Report for OSTF-1 Program EMA Testing, June 1961 (15 July 1961), Van Nuys OSTF
	August	REM 1181-5556, OSTF-1 Summary Analysis Report, July 1961 (31 August 1961), VAFB OSTF
	September	REM 1181-1559, OSTF-1 Summary Analysis Report, August 1961 (15 September 1961), VAFB OSTF
	October	ROM 1181-1001, OSTF-1 Summary Analysis Report, September 1961 (15 October 1961, VAFB OSTF
	November	ROM 1181-1006, OSTF-1 Summary Analysis Report, October 1961 (15 November 1961, VAFB OSTF
	December	ROM 1181-1007, OSTF-1 Summary Analysis Report, November 1961 (15 December 1961), VAFB OSTF
		ROM 1181-1008, OSTF-1 Countdown Series, Logical Function Report on Personnel Subsystem Objectives (29 December 1961), VAFB OSTF
1962:	January	R-3450-1, OSTF-1 Periodic Report on Personnel Subsystem Objectives (30 January 1962), VAFB OSTF
	February	R-3450-2, OSTF-1 Periodic Report for January 1962 on Personnel Subsystem Objectives (28 February 1962)
	March	R-3450-3, OSTF-1 Periodic Report for February 1962 on Personnel Subsystem Objectives (30 March 1962)

April	R-3569-1, OSTF-2 Human Factors-Personnel Subsystem Report for March 1962 (15 April 1962)
	R-3450-4, OSTF-1 Periodic Report for March 1962 on Personnel Subsystem Objectives (30 April 1962)
May	R-3569-2, OSTF-2 Human Factors-Personnel Subsystem Report for April 1962 (15 May 1962)
	R-3450-5, OSTF-1 Periodic Report for April 1962 on Personnel Subsystem Objectives (30 May 1962)
	R-3520, OSTF Test and Evaluation Program for the Atlas MA-3 Engine Maintenance Area
June	R-3569-3, OSTF-2 Human Factors-Personnel Subsystem Report for May 1962 (15 June 1962)
	R-3450-6, OSTF-1 Periodic Report for May 1962 on Personnel Subsystem Objectives (30 June 1962)
July	R-3569-4, OSTF-2 Human Factors-Personnel Subsystem Report for June 1962 (15 July 1962)
	R-3450-7, OSTF-1 Periodic Report for June 1962 on Personnel Subsystem Objectives (30 July 1962)
August	R-3737, OSTF-1 Logical Function Report, Missile Maintenance-in-Readiness, Human Factors-Personnel Subsystem Objectives (13 August 1962)
	R-3774, OSTF-1 Logical Function Report, Launch Area Preparation and Checkout, Human Factors-Personnel Subsystem Objectives (13 August 1962)

		R-3569-5, OSTF-2 Human Factors-Personnel Subsystem Report for July 1962 (15 August 1962)
		R-3450-8, OSTF-1 Periodic Report for July 1962 on Personnel Subsystem Objectives (30 August 1962)
	September	R-3569-6, OSTF-2 Human Factors-Personnel Subsystem Report for August 1962 (15 September 1962)
		R-3450-9, OSTF-1 Periodic Report for August 1962 on Personnel Subsystem Objectives (30 September)
	October	R-3569-7, OSTF-2 Human Factors-Personnel Subsystem Report for September 1962 (15 October 1962)
		R-3450-10, OSTF-1 Periodic Report for September 1962 on Personnel Subsystem Objectives (30 October 1962)
	November	R-3569-8, OSTF-2 Human Factors-Personnel Subsystem Report for October 1962 (15 November 1962
		R-3450-11, OSTF-1 Periodic Report for October 1962 on Personnel Subsystem Objectives (30 November 1962)
	December	R-3569-9, OSTF-2 Human Factors-Personnel Subsystem Report for November 1962 (15 December 1962)
1963:	January	R-3569-10, OSTF-2 Human Factors-Personnel Subsystem Report for December 1962 (15 January 1963)
	February	R-3369-11, OSTF-2 Human Factors-Personnel Subsystem Report for January 1963 (15 February 1963)

APPENDIX F

RELATED REFERENCES

The following references contain information which is related to the designated portions of the text. These references are provided so that the interested reader may be able to gain initial access to representative portions of the technical literature dealing with each area of activity, obtain further amplification of some of the basic methodological concepts presented, clarify or gain better undersanding of some of the technical details mentioned, or to derive a better perspective of the nature of the procedures described in this report.

SYSTEMS ANALYSIS

1. Van Cott, H. P. and J. W. Altman: Procedures for Including Human Engineering Factors in the Development of Weapon Systems, WADC Technical Report 56-488, (AD-97305), Wright-Patterson Air Force Base, Ohio, October 1956.

2. Kearns, J. H. and M. L. Ritchie: Cockpit Control-Display Subsystem Engineering, ASD Technical Report 61-545, Wright-Patterson Air Force Base, Ohio, October 1961.

3. Sinaiko, H. W. and E. P. Buckley: Human Factors in the Design of Systems, NRL Report 4996. Naval Research Laboratory, Washington, D. C., August 1957.

4. Shapero, A. and C. Bates: A Method for Performing Human Engineering Analysis of Weapon Systems, WADC Technical Report 59-784, Wright-Patterson Air Force Base, Ohio, September 1959.

5. Aerospace System Personnel-Equipment Data for Personnel Subsystem Development, AFBM Exhibit 60-65A, 17 November 1961.

6. Data for Aeronautical Weapon Systems and Support Systems. MIL-D-9310B(USAF).

7. Data for Aerospace Ground Equipment (AGE), MIL-D-9412D(USAF), 27 September 1961.

8. Instructions for the Preparation of Minuteman, WS-133A and WS-133A-M, Ground Operational and Support System Specifications, AF/BSD 61-56, 6 March 1962.

9. Weapon Systems: Aeronautical, General Specification for, MIL-W-9411A(USAF).

10. Maintainability Requirements for Aerospace Systems and Equipment, MIL-M-26512B(USAF), 23 March 1962.

11. Human Engineering: General Specification for the Development of Air Force Ballistic Missile Systems, AF/BSD Exhibit 61-99, 1 February 1962.

12. Lindquist, O. H. and R. L. Gross: Human Engineering Man-Machine Study of a Weapon System, MH Aero Report R-ED 6094, Minneapolis-Honeywell Regulator Co., Minneapolis, Minnesota, October 1958.

HUMAN ERROR

1. Shapero, A., J. I. Cooper, M. Rappaport, K. H. Schaeffer, and C. Bates: Human Engineering Testing and Malfunction Data Collection in Weapon System Test Programs, WADD Technical Report 60-36, Wright-Patterson Air Force Base, Ohio, February 1960.

2. Chapanis, A.: "Methods for the Study of Accidents and Near Accidents," Chapter 3 in Research Techniques in Human Engineering, The Johns Hopkins Press, Baltimore, Maryland, 1959.

3. Meister, D.: Human Reliability Production Audit. Proceedings of the Ninth National Symposium on Reliability and Quality Control, San Francisco, California, January 22-24, 1963, 194-191.

4. Brady, J. S.: Application of a Personnel Personnel Performance Metric, Proceedings of the IAS Aerospace Systems Reliability Symposium, Salt Lake City, Utah, April 16-18, 1962, 215-219 (NASA 62-16223).

SYSTEMS TEST

1. McAbee, W. H.: A Bibliography of Research Reports and Publications in the Areas of Human Performance and Personnel Subsystem Test and Evaluation, PGN Document 62-3, Eglin Air Force Base, August 1962.

2. Manley, R. W.: Maintainability of the Falcon Missile System, SAE Preprint 93C, presented at the Society of Automotive Engineers, National Aeronautic Meeting, Los Angeles, California, October 1958.

3. Meister, D.: The Measurement of Man-Machine Systems Under Field Operational Conditions, General Dynamics/Astronautics, San Diego, California, 1 June 1961.

4. AFR 80-14, Category II Test Program Plan for Ballistic Missiles, 13 April 1961.

5. GD/A Report AE60-0806, Integrated Test Plan for Operational Systems Test Facilities, OSTF-1, Part II, 21 December 1960, CONFIDENTIAL.

6. STL Report GM 6300.5-1060, Personnel Subsystem Test Plan Annex, 15 December 1960.

7. AFBMD Exhibit 60-1, Personnel Subsystem Testing for Ballistic Missile and Space Systems, 22 April 1960.

MOTIVATION

1. Thibodo, D. R. and M. L. Nigberg: Effective Indoctrination to Accelerate the Acceptance of Reliability Controls, Proceedings of the IAS Aerospace Systems Reliability Symposium, Salt Lake City, Utah, April 16-18, 1962, 183-190 (NASA N62-16218).

SAFETY IN DESIGN

Publications issued by Flight Safety Foundation, Inc., 468 Fourth Ave., New York 16, New York:

1. Human Factors Bulletins
2. Design Notes
3. Air Safety Digests
4. Newsletters
5. Accident Prevention Bulletins
6. Aviation Mechanics Bulletins
7. Safety Exchange Bulletins
8. Publications Index and Membership Roster

PERSONNEL SUBSYSTEM

1. Majesty, M. S.: Personnel Subsystem Reliability for Aerospace Systems, Proceedings of the IAS Aerospace System Reliability Symposium, Salt Lake City, Utah, April 16-18, 1962, 199-204 (NASA N62-16220).

2. Handbook of Instructions for Aerospace Personnel Subsystem Designers, AFSCM 80-3, July 1962.

3. Rabideau, G. F.: Prediction of Personal Subsystem Reliability Early in the System Development Cycle, Proceedings of the IAS Aerospace Systems Reliability Symposium, Salt Lake City, Utah, April 16-18, 1962, 199-198 (NASA N62-16219).

4. Personnel Subsystem Management, Joint ARDC-ATC Policy on Management of Personnel Subsystem Development for Weapon/Supporting Systems, 1 February 1960.

APPENDIX G

HUMAN FACTORS AND SAFETY PROBLEM CROSS REFERENCE

Human Factors Problem No.	Safety Problem No.	Human Factors Problem No.	Safety Problem No.
16	16	223	11
19	3	227	13
57	14	230	4
60	17	231	8
71	18	235	27
85	19	236	39
86	20	237	26
88	21	243	29
98	5	248	35
111	2	254	34
121	22	255	30
129	28	262	31
140	23	272	43
148	9	274	33
154	7	276	32
155	47	279	1
166	24	283	10
168	42	284	40
199	46	285	12
206	25	288	38
211	44	290	41
213	45	291	37
216	36	302	6
221	15		